Appendix B

Human Health Fate and Transport Models, Transport Factors, and Reduction Factors

Appendix B1

Additional Evaluation of Exposure to PCBs in Fish from the Lower Fox River and Green Bay

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Table of Contents

Table of Contents

List of Tables

List of Tables

List of Figures

List of Figures

List of Figures

List of Figures

List of Figures

1 Introduction

This appendix expands upon the focused evaluation of exposure to PCBs in fish provided in Section 5.9 of the main report. The focused evaluation of exposure to PCBs in fish examined exposures for two categories of anglers (recreational anglers and high intake fish consumers), for five different categories of fish (all fish data, carp, perch, walleye and white bass) and for the four reaches of the Lower Fox River (Little Lake Butte des Morts, Appleton to Little Rapids, Little Rapids to De Pere, and De Pere to Green Bay) and three zones of Green Bay (zones 3A, 3B and 4). In the main report, for each category of angler, intake assumptions were developed for two exposure scenarios: reasonable maximum exposures (RMEs) and central tendency exposures (CTEs). For each intake parameter, a distribution of values was developed and point values were selected from the distribution for the RME and CTE scenarios. For a number of parameters, the 90^{th} or 95^{th} percentile was selected as the point estimates for the RME scenario while for other parameters, the mean or median was selected as the point estimate for the RME scenario. For the CTE scenario, mean or median values were selected as the point estimate for all parameters. These point estimates for individual parameters were used in Section 5.9 to generate point estimates of risk and hazard index for the RME and CTE scenarios. Point estimates of risk and hazard index were generated for each category of angler, for the different categories of fish and for the various reaches and zones of the Lower Fox River and Green Bay.

Section 2 of this appendix provides the equations used to calculate exposures, risks and hazard indices for the two categories of anglers. This section also discusses the distributions utilized for each intake parameter and the RME and CTE point estimates selected for each parameter from the distribution for each parameter.

On behalf of the Fox River Group (FRG), Exponent, Inc. prepared a human health risk assessment for the Lower Fox River. In their risk assessment, Exponent (2000) developed distributions for a variety of intake parameters and used those distributions to develop distributions of risks and hazard indices. Exponent (2000) did not use the distributions to select RME and CTE values and then calculate point estimates of the risks and hazard indices for these two scenarios. In Section 3 of this appendix, RME and CTE values are selected for each intake parameter using the distributions provided by Exponent (2000). Using the selected values, point estimates of risks and hazard indices are calculated for the RME and CTE scenarios. These point estimates of risks and hazard indices are

then compared to the point estimates of risks and hazard indices calculated in the focused evaluation in Section 5.9 of the main report.

Section 4 of this appendix presents a probabilistic evaluation for the recreational angler and high intake fish consumer based on the distributions of intake parameters presented in Section 2 of this appendix. Since the probabilistic risk assessment develops distributions of risks and hazard indices, the location on the distributions of the point estimates of risk and hazard index using RME and CTE values can be ascertained. This allows the RME and CTE point estimates of risks and hazard indices to be placed in the range of risks calculated using probabilistic methods and provides a context for interpreting the point estimates of risks and hazard indices.

It is important to emphasize that the probabilistic risk assessment is not intended to be the principal basis for decisions regarding the need for remedial action at a site. EPA guidance specifies that point estimates of risks and hazard indices calculated using point estimates of intake parameters for RME and CTE scenarios are the principal basis for such decisions. Therefore, the probabilistic risk assessment does not supercede the point estimate evaluation, but is intended to supplement and complement the point estimates of risks and hazard indices. The probabilistic risk assessment has considered draft EPA guidance on probabilistic risk assessment (EPA, 1999).

Section 5 of this appendix provides the references cited in the appendix.

2 Basic Equations and Intake Parameters

This section presents the basic equations for calculating risks and hazard indices for receptors potentially exposed to PCBs present in fish in the Lower Fox River and Green Bay. The notation used is consistent with that used in the main report. In addition, this section discusses the concepts of variability and uncertainty, as well as the choice of the distribution for each intake parameter used in the probabilistic assessment presented in Section 4 of this appendix.

2.1 Equations for Calculating Cancer Risks and Hazard Indices

2.1.1 Cancer Risk Evaluation

The equation used to assess cancer risks from ingestion of fish is:

$$R = Ic \cdot CSFo$$

where:

R = cancer risk
Ic = intake from ingestion of fish averaged over a lifetime (mg/kg-day)
CSFo = oral cancer slope factor [$(mg/kg\text{-}day)^{-1}$]

The intake from fish ingestion averaged over a lifetime is given by:

$$Ic = \frac{Cfish \cdot IR \cdot RF \cdot ABS \cdot CF \cdot EF \cdot ED}{BW \cdot ATc}$$

where:

Cfish = concentration in fish (mg/kg)
IR = fish ingestion rate (g/day or g/meal)
RF = reduction factor due to trimming and cooking fish (mg/mg)
ABS = absorption factor for ingestion of fish (mg/mg)
CF = 10^{-3} kg/g
EF = exposure frequency (days/year or meals/year)
ED= exposure duration (years)
BW = body weight (kg)

ATc = averaging time for cancer risks (days)

The intake equation can be rewritten as:

$$Ic = Cfish \cdot IntFacC$$

$$IntFacC = \frac{IR \cdot RF \cdot ABS \cdot CF \cdot EF \cdot ED}{BW \cdot ATc}$$

where:

IntFacC = intake factor for cancer risk [$(mg/kg)^{-1}$]

The equation for assessing cancer risks from ingestion of fish can be rewritten as:

$$R = Cfish \cdot IntFacC \cdot CSFo$$

2.1.2 Noncancer Effects Evaluation

The equation for calculating the chronic hazard index from ingestion of fish is:

$$HI = \frac{Inc}{RfDo}$$

where:

HI = chronic, noncancer hazard index
Inc = intake from ingestion of fish averaged over the exposure period (mg/kg-day)
RfDo = oral reference dose for chronic, noncancer effects (mg/kg-day)

The intake from fish ingestion averaged over the exposure period is given by:

$$Inc = \frac{Cfish \cdot IR \cdot RF \cdot ABS \cdot CF \cdot EF \cdot ED}{BW \cdot ATnc}$$

These variables are the same as before except:

ATnc = averaging time for chronic, noncancer effects (days)

The intake equation can be rewritten:

$$Inc = Cfish \cdot IntFacNC$$

$$IntFacNC = \frac{IR \cdot RF \cdot ABS \cdot CF \cdot EF \cdot ED}{BW \cdot ATnc}$$

where:

IntFacNC = intake factor for chronic, noncancer effects [$(mg/kg)^{-1}$]

The equation for calculating the chronic hazard index from ingestion of fish can be rewritten as:

$$HI = \frac{Cfish \cdot IntFacNC}{RfDo}$$

2.2 Variability and Uncertainty

In Section 2.1, the equations used to calculate intakes and estimate cancer risks and noncancer hazard indices were presented. A number of parameters appear in the intake equations. For almost all of these parameters, a single fixed value does not definitively characterize the parameters. Instead, a distribution of values is a more appropriate choice for representing the parameter. The value selected for the parameter in a point estimate analysis depends on the objectives of a particular analysis. A distribution of values exists for most parameters due to variability, uncertainty or both. The concepts of variability and uncertainty, as applied to probabilistic risk assessment, are defined in EPA (1999) as follows (pages 1-3 and 1-4):

- Variability: True heterogeneity or diversity that characterizes an exposure variable or response in a population. Further study (e.g., increasing sample size, n) will not reduce variability, but it can provide greater confidence in quantitative characterization of variability.

- Uncertainty: Lack of knowledge about specific variables, parameters, models, or other factors (e.g., uncertainty regarding the concentration of a contaminant in an environmental medium, local fish consumption practices). Uncertainty may be reduced through further study.

To illustrate the difference in variability and uncertainty, consider the parameters fish ingestion rate (IR) and exposure frequency (EF). When multiplied together, these parameters yield the quantity of self-caught fish that an angler consumes in a year. It is known that in the population of recreational anglers, there is a

considerable range in the amount of fish consumed annually by recreational anglers. Some anglers eat none of the fish they catch, while other anglers eat many meals of self-caught fish each year. This range in annual fish consumption rates is inherent to the population of recreational anglers and reflects the variability in annual fish consumption rates in the recreational angler population. A number of surveys of recreational anglers have been conducted to define the distribution of annual fish consumption rates for recreational anglers. Each survey generates a somewhat different distribution of annual fish consumption rates and the differences in the various distributions reflect the uncertainty in the characterization of variability.

EPA guidance (1999) indicates that probabilistic risk assessments should attempt to isolate the influences of variability and uncertainty on the calculation of risks and hazard indices. This guidance (EPA, 1999) recommends performing one dimensional or two dimensional probabilistic assessment. In a one dimensional probabilistic assessment, distributions are assigned to parameters to characterize the variability in each parameter. If there is uncertainty in the distribution that should be assigned to a specific parameter, this can be evaluated by performing multiple one dimensional analyses with different distributions assigned to a parameter in each analysis. In theory, the evaluation of uncertainty can be taken one step further. Distributions can be assigned to variables that are uncertain and the influence of uncertainty can be evaluated in a two dimensional probabilistic assessment. For example, if the variability in a parameter is characterized by a normal distribution, but there is uncertainty associated with the mean and standard deviation that define this normal distribution, then the uncertainty can be expressed by assigning distributions to the mean and standard deviation. In a two dimensional probabilistic assessment, values for the mean and standard deviation are randomly selected from the distributions for these variables and these values are used to perform a probabilistic risk assessment to characterize the variability associated with these values. Then new values for the mean and standard deviation are chosen and the process is repeated. The outcome of a one dimensional probabilistic risk assessment is typically a single distribution characterizing the range in risk (or hazard index). The outcome of an uncertainty analysis (either multiple one dimensional probabilistic risk assessments or a two dimensional probabilistic risk assessment)is a series of distributions characterizing both the range in risk (or hazard index) and the uncertainty associated with this range.

In the probabilistic analysis presented in this appendix, an attempt has been made to characterize the variability inherent in a number of parameters by using probability distributions for the variable parameters and performing one dimensional probabilistic risk assessments. By doing so, the likelihood of different

risks in a potentially exposed population was quantified. The probability distributions of risks and hazard indices presented in Section 4 can be used to answer the question "what is the probability that the risks (or hazard indices) will exceed a regulatory level of concern (e.g., 10^{-5} or 10^{-6})?"

It should be noted that in the analysis presented in this appendix, for all parameters but one, no attempt has been made to quantify uncertainty. The only quantity for which uncertainty has been incorporated in the analysis is the average yearly quantity of fish ingested by the receptor population (g/year) (this is the product of two parameters, the daily fish ingestion rate and the exposure frequency). For this quantity, probability distributions of risks and hazard indices were generated based on fish ingestion rates calculated in various studies (see Section 2.4). The probability distributions obtained based on each study were then combined and used to estimate the uncertainty in the risk and hazard index estimates using a procedure recommended in EPA (1999) (see Section 4).

Section 2-3 reviews each intake parameter. The assumptions used for fish intake rate and exposure frequency are examined in more detail in Section 2.4. As discussed above, the results of the various studies consulted were used to evaluate the uncertainty in the risks and hazard indices. Attachment 1 provides summary statistics tables and histogram plots for all input distributions used in the probabilistic risk evaluation.

2.3 Intake Parameter Evaluation

2.3.1 Fish Concentration (Cfish)

The parameter Cfish represents the mean concentration of PCBs in fish consumed by anglers over the exposure period. Tables 2-1 through 2-3 present the distributions of Cfish used in the analysis presented in this appendix. Table 2-1 describes the distribution of fish concentration used by Exponent (2000), which represents fish fillet (no skin) data collected from the entire Lower Fox River. ThermoRetec calculated exposures to anglers for different reaches of the Lower Fox River and zones of Green Bay. For this evaluation, distributions were developed for the Little Lake Butte des Morts (Table 2-2) and De Pere to Green Bay (Table 2-3) reaches using all fish fillet data (most of these samples were fillet with skin). These reaches are the most populated and likely to have the most anglers.

It is recognized that there is wide variability in the PCB concentrations in fish caught in the Lower Fox River. There is also variability associated with the mean concentration in fish consumed by anglers over the exposure period (which

represents the exposure point concentration in the probabilistic risk assessment). This can be understood with the following considerations.

If a large number of anglers (say, a thousand) were engaged in a study and the concentration of total PCBs in each self-caught fish the angler consumed was determined over a long period of time (such as a 10 year period), an average concentration of total PCBs in fish could be determined for each angler. These data could then be used to determine a distribution of the mean concentration of total PCBs in fish for the angler population. There are at least three sources of this variability.

- Variability of concentrations in a species: The concentrations of total PCBs in fish of the same species vary considerably based on analysis of samples from different fish of the same species. This variability is due to a number of factors including the age of the fish, the length of time the fish has spent in the Lower Fox River or Green Bay, the intrinsic biochemical process such as metabolism and depuration in the individual fish, and the mix of food (zooplankton, benthic invertebrates, fish) the fish consumes.

- Variability between species: The concentrations of total PCBs in fish vary between species. For example, the concentration of total PCBs in carp is greater on average than the concentration of total PCBs in bass, perch or walleye. This variability can be characterized by analyzing samples from different fish species.

- Mix of fish the angler consumes: Based on surveys, the mix of fish species that angler populations consume has been characterized. In general, this survey data is presented for the angler population as a whole. For example, Hutchison and Kraft (1994) report that only 2% of the fish caught by Hmong anglers is carp. What is not known is whether a small number of Hmong anglers eat a substantial amount of carp and all other Hmong anglers eat virtually no carp (scenario 1) or a large number of Hmong anglers eat a small amount of carp (scenario 2). The first scenario leads to a small number of anglers eating fish with significantly higher concentrations of total PCBs than more commonly consumed fish species such as bass, perch and walleye. This scenario leads to a larger range in the mean concentration in fish that anglers are exposed to than does the second scenario. The mix of fish consumed by individual anglers is therefore both variable and uncertain.

If all other factors are held constant, the variability in the mean PCB concentration in fish consumed by anglers over the study period will be greater for anglers who eat a small number of meals over the study period than for anglers who eat a large number of meals over the same period. As more fish are consumed, the standard deviation on the distribution of the mean PCB concentration (Cfish) will become smaller.

ThermoRetec and Exponent (2000) have taken different approaches to estimate Cfish. These approaches are discussed below.

Exponent (2000)

Exponent (2000) did not distinguish between reaches in the Lower Fox River, and used a distribution for the fish PCB concentration that is representative of the time averaged concentration in fish that are caught and eaten after each fishing trip. The sampling distribution for the arithmetic mean was used to describe the PCB concentration in fish tissue. For each species of fish, this distribution was taken as normal with a mean equal to the sample mean, and a standard deviation equal to the sample standard deviation divided by the square root of the number of values for which the sample mean was calculated. To constrain the distribution to physically relevant values, the distribution was truncated at a minimum of zero and a maximum of three standard deviations above the mean. Distributions were calculated for a number of species and added up; distributions were then weighted by the fraction of times the fish species was determined to be consumed. The weighting factors used by Exponent were:

- Walleye: 0.26
- Smallmouth Bass: 0.03
- Yellow perch: 0.70
- Brown trout: 0.01

In addition, Exponent assumed that the average PCB concentration in fish is decreasing exponentially over time. The average concentration for each fish species over the exposure period was taken as the exposure point concentration. This concentration is lower than the concentration measured in fish today, as fish concentration is assumed to decrease over the exposure period. The rates at which fish concentrations were assumed to decrease are as follows:

- Walleye: 0.058/year (half life of 12 years)
- Smallmouth Bass: 0.116/year (half life of 6 years)
- Yellow perch: 1.16/year (half life of 6 years)
- Brown trout: 0.12/year (half life of 5.8 years)

It should be noted that Exponent (2000) was essentially characterizing the uncertainty in the mean and not the variability. In exponents approach, if more fish samples were collected, the standard deviation would decrease which is a characteristic of uncertainty. Also, in their approach, the uncertainty in the PCB concentration in fish consumed by anglers is assumed to be independent of the number of meals consumed over the exposure period. This is not consistent with the results that would be obtained by performing the thought experiment described above.

ThermoRetec

In determining the average PCB concentration in fish consumed by Lower Fox River and Green Bay anglers, ThermoRetec simulated numerically the thought experiment described above. The procedure used by ThermoRetec is described below.

- The anglers were assumed to catch all their fish from either the Little Lake Butte des Morts or the De Pere to Green Bay reach. All fillet data for the 1990s from each reach were used as the data set for each reach on the assumption that more commonly consumed fish species were caught and tested during this time period. For each dataset, the mean and standard deviation were calculated.

- For each reach, it was assumed that the mean and standard deviation of the fish data represents the variability inherent in fish caught by anglers over the exposure period and consumed in a single meal. This distribution was assumed to be constant over the exposure period, i.e., no decreases over time were assumed.

- The mean PCB concentration in fish to which an individual angler is exposed over the exposure period was determined by calculating the distribution of the mean of the single-meal PCB fish concentration over the number of meals consumed during the exposure period. Since for the majority of anglers the assumed number of meals over the exposure period is large (greater then 100), the distribution of the mean fish concentration over the exposure period was calculated (using the central limit theorem, confirmed by numerical experimentation) as a normal distribution with mean equal to the mean of the fish concentration within each reach, and standard deviation equal to the standard deviation of the fish concentration within each reach divided by the square root of the number of meals consumed. The distributions were truncated at minimum and maximum values equal to the minimum and maximum values measured within each reach (see Tables 2-2 and 2-3).

- It should be noted that by assuming that all anglers catch fish from the same pool of fish, it is assumed that all anglers have the same preference for individual fish species. If some anglers prefer carp to all other fish, their average PCB concentration would be higher than the average for other anglers. Thus, this procedure underestimates the variability in the mean PCB concentration associated with the fact that some anglers may eat more fish of one species than other anglers.

The procedure used by ThermoRetec is consistent with the results that would be obtained by performing the thought experiment described earlier. It should be noted that as the number of meals increases, the variability in the mean fish concentration decreases (as measured by the standard deviation of the distribution of the mean), as is expected based on the thought experiment previously described.

It should also be noted that ThermoRetec's procedure does not include an evaluation of uncertainty in the mean fish concentration, and that the distribution used for the mean PCB concentration to which anglers are exposed only represents the variability of this parameter.

2.3.2 Fish Ingestion Rate (IR) and Exposure Frequency (EF)

These parameters are the amount of fish consumed per meal (IR) and the exposure frequency (EF) or meals per year. Both parameters are known to vary within the angling population, and both parameters can be characterized by surveys of anglers. Many surveys, however, only characterize the number of fish meals per year (or in a shorter period), so the meal size must be estimated from other sources. In many studies, the estimates of IR and EF are multiplied together to give the mass of fish consumed per year, and this result is then divided by 365 days/years to give an annualized IR. The distribution of this annualized IR (in g/day) is the final published result.

The data summarized in this appendix utilizes information gleaned from studies that used both approaches. As such, depending on the study cited, IR is given in either g/day or g/meal, and EF is given in either days/year or meals/year. Regardless, the product IR*EF is always in g/year.

It should also be noted that EF or a normalized IR should reflect the number of meals of fish caught from the Lower Fox River or Green Bay. It is known that the Lower Fox River and Green Bay are not the only water bodies used for fishing by anglers living in the region. Surveys can quantify existing behavior and the data used by Exponent (2000) uses survey results for the Lower Fox River. However, it is known from other surveys (e.g., Hutchison, 1999) that the behavior of

anglers has been modified by fish consumption advisories on the Lower Fox River and Green Bay. These advisories affect 1) the frequency of fishing on these water bodies; 2) whether fish are kept for consumption or returned to the water body; and 3) the type of fish kept for consumption. A baseline evaluation should estimate what potential exposures would be in the absence of such advisories. Thus, survey data from the Lower Fox River should not be used unless these data are adjusted in some manner to account for the influence of fish advisories on sport-fish consumption patterns. If such data are used without adjustment, the risks and hazard indices calculated with these data will underestimate the risks and hazard indices that would result if the advisories were lifted. Therefore, these results must be used with caution.

The distributions of IR and EF used in the probabilistic risk evaluation are discussed in Section 2.4 based on studies of different angler populations. As discussed in Section 2.4, different studies report different results for the average fish intake. Within each study, IR and EF are characterized by variability. That is, different receptors have different fish intakes, according to the various published distributions. However, the fact that different studies report different results indicates that some uncertainty is present in the estimation of intake rates. Thus, the product IR*EF is characterized by both uncertainty and variability. Both are accounted for in ThermoRetec's analysis, as discussed in Section 4.

2.3.3 Reduction Factor (RF)

The reduction factor represents the fraction of the initial mass of PCBs in fish that remains after trimming and cooking. In this appendix, a distinction is made between the reduction factor for fish consumed in a single meal (referred to as the single-meal reduction factor) and the mean reduction factor over a number of meals. The latter is the parameter relevant to the risk assessment calculation and is referred to as the mean reduction factor, designated by the variable RF.

It is recognized that variability is associated with the single-meal reduction factor for fish caught in the Lower Fox River or Green Bay, cooked, trimmed and then consumed by local anglers. As a consequence, variability is also associated with the mean reduction factor in fish consumed by anglers (RF) which is used in the risk assessment.

Losses due to trimming and cooking are a source of variability. For an individual angler, the losses can vary between meals depending on how the angler prepares and cooks the fish. In addition, different anglers may use preferentially different cooking and trimming techniques. As such, the single-meal reduction factor is characterized by inherent variability among the angling population. If a large number of anglers (say, a thousand) were engaged in a study and the reduction

in mass of total PCBs was measured from the raw fish to the final trimmed and cooked product in each meal the angler ate, an average single-meal reduction factor could be determined for each angler. These data could then be used to determine a distribution of the reduction factor for all anglers. This experiment has not been performed; however, data are available on the reduction in PCB concentrations in fish due to trimming and cooking techniques.

If all other factors are held constant, the variability in the mean reduction factor in fish consumed by anglers (which is used in the risk assessment) will be greater for anglers who eat a small number of meals over the study period than for anglers who eat a large number of meals over the same period. As more fish is consumed, the standard deviation on the distribution of RF will become smaller. As such, the distribution of RF is a function of the number of fish meals consumed by anglers over the exposure period.

Table 2-4 presents the distributions used for the RF used by Exponent (2000) and ThermoRetec. These distributions are discussed below.

Exponent (2000)

Exponent (2000) used only fillet with no skin data in estimating their fish concentration. Consequently, Exponent (2000) used a distribution for RF that reflects losses from cooking only. This reduction factor was developed by Wilson et al. (1998) based on reductions observed from cooking fish. Exponent used a cumulative distribution with a mean of 0.635, maximum of 1 (corresponding to no reduction in the PCB concentration in fish), and minimum of 0 (corresponding to 100% reduction in the PCB concentration in fish).

It should be noted that in the risk assessment, Exponent used the distribution for the single-meal reduction factor, rather than the distribution for the mean reduction factor over the meals consumed during the exposure period.

ThermoRetec

When ThermoRetec fish concentration data are used, a reduction factor reflecting losses due to trimming as well as cooking is needed, because the ThermoRetec fish concentration distribution was developed from fish concentration data that are primarily fillet with skin data.

As previously discussed, the reduction factor is a function of how fish is trimmed and how it is cooked (e.g., broiled vs. fried). It is reasonable to expect that each individual angler will not trim and cook fish always in the same manner. As such, the reduction factor will vary according to a certain probability distribution.

To estimate this probability distribution, ThermoRetec made the following assumptions.

- Trimming is generally performed by anglers prior to cooking the caught fish.

- The reduction factor estimated by Wilson et al. (1998) for fillet with no skin can be used for estimating the reduction factor in fish already trimmed.

Based on the first assumption, the reduction factor due to cooking and trimming can be expressed as:

$$\text{Single-Meal Reduction Factor} = RF_{trim} * RF_{cook}$$

Where RF_{trim} represents the fraction of PCB mass remaining in fish after trimming (single-meal), and RF_{cook} represents the fraction remaining after cooking (single-meal).

Based on the second assumption, RF_{cook} was taken to be distributed according to the data presented in Wilson et al. (1998), consistent with Exponent (2000) assumptions. Limited data are available specifically on RF_{trim} and these data have not been reviewed and compiled by investigators with the same level of scrutiny as for RF_{cook}. However, based on information published in Anderson et al. (1993), the average of the single-meal reduction factor due to the combined effect of trimming and cooking is likely to be approximately 50%. Thus, RF_{trim} was chosen such that the average of $RF_{trim} * RF_{cook}$ is 50%. Since, based on the distribution presented in Wilson et al. (1998), the average of RF_{cook} is 63.5%, a distribution was assumed for RF_{trim} whose average is 78.7%. This distribution was assumed to be uniform with a variation of plus or minus 19.7% (which represents 25% of the average value) around the average value of 78.7%. The single-meal reduction factor was therefore taken as the product of the cumulative distribution described in Table 2-4a, and a uniform probability distribution with maximum and minimum values of 59% and 98.4%.

As previously discussed, the distribution discussed above represents the variability in the overall reduction factor associated with generally cooking and trimming fish in a single meal. The distribution of the mean single-meal reduction factor in fish consumed by anglers (RF) depends on the number of meals consumed by anglers over the exposure period.

Similar to what was assumed for Cfish, the mean reduction factor for an individual angler over the exposure period was calculated by estimating the distribution of the mean of the single-meal reduction factor over the number of meals consumed during the exposure period. Since for the great majority of anglers, the assumed number of meals over the exposure period is large (greater then 100), the distribution of the mean reduction factor over the exposure period was calculated (using the central limit theorem) as a normal distribution, with mean equal to the mean of the single-meal reduction factor (0.5) and standard deviation equal to the standard deviation of the single-meal reduction factor (0.2) divided by the square root of the number of meals consumed (see Table 2-4b).

It should be noted that this procedure assumes that all anglers trim and cook fish in a similar way. If some anglers trim less and cook fish in a stew on a regular basis, their average reduction factor would be higher (i.e., less PCBs would be lost) than estimated here. Therefore, this procedure tends to underestimate variability.

It should also be noted that ThermoRetec's procedure does not include an evaluation of uncertainty in the mean reduction factor, and that the distribution used for the mean reduction factor to which anglers are exposed only represents the variability of this parameter.

2.3.4 Absorption Efficiency (ABS)

The absorption efficiency is based on the studies used to generate the cancer slope factors and reference doses for PCBs. In general, PCBs in fish are considered to be fairly readily assimilated when ingested, and the vehicle for delivering PCBs to the animals used to develop the cancer slope factor and reference dose for total PCBs also resulted in significant absorption as discussed in Section 5 of the main report. Therefore, it was assumed that all PCBs in ingested fish were assimilated by the body in a manner similar to the animals used to develop the cancer slope factors and reference doses, so ABS was set to 1. This same assumption was used in Exponent (2000).

2.3.5 Exposure Duration (ED)

The exposure duration represents the number of years that the angler pursues angling. More specifically, the exposure duration is the number of years an angler catches fish at the rates specified by IR and EF. Variability is associated with ED. For the population of anglers, ED will vary since some anglers will start fishing later in life and continue fishing for a short period of time and others will begin fishing when they are young and continue fishing for their whole lives. The parameter also depends on how long the angler lives in the study area. Thus, the parameter ED depends on: when anglers begin fishing during their lifetime; the

number of years they engage in fishing; and the number of years they remain in the Lower Fox River and Green Bay area and therefore, have the opportunity to fish from these water bodies on a regular basis.

Exponent (2000)

Table 2-5 presents the distribution of exposure duration used by Exponent (2000). Exponent (2000) developed a distribution for ED based on the survey data they had for the Fox River using the methodology of Price et al. (1998). A limitation of this method is that it depends on the survey data collected from the Lower Fox River, since it is known that angler behavior has been affected by the existence of fish advisories for the Lower Fox River and Green Bay, as discussed previously.

ThermoRetec

Table 2-6 presents the distribution of exposure duration used by ThermoRetec. ThermoRetec developed a distribution for ED based on data for residence time and information on where people move. EPA (1997) provides data on the time people spend in one residence (Table 2-7). EPA (1997) also provides data on where people move when they change residences. In general, 62 percent of the time people move within the same county, 18.5 percent of the time they move to a different county within the same state, and the remaining moves are to a different state or out of the country. These data were used to simulate the moves of an individual from one residence to another. The following process was simulated:

1) The process begins (i.e., time zero is established) when the individual enters the region (either through birth or a move into the region).

2) If i is a number representing the i^{th} residence since entering into the region, set i to 1 at time 0.

3) For the i^{th} residence determine the time spent at this residence (T_i) by picking a value randomly from the distribution of time spent in a residence (see Table 2-7).

4) Determine if the move from the i to the $i+1$ residence is within the region or out of the region. This is accomplished by selecting a value randomly from a discrete distribution described below that is either a 1 (move is within region) or a 0 (move is out of region). If the move is out of the region, it is assumed that the individual never returns to the region, so the time in a residence within the region for the $i+1$ residence and all subsequent residences is set to 0.

5) Steps 3 and 4 are repeated until the individual moves out of the region or the individual dies (i.e., the age when entering the region plus the total time spent in the region exceeds the years in a lifetime).

There are two critical assumptions needed to execute this simulation. First, the age of the individual when they enter the region must be specified. Second, the distribution specifying whether a move is within the region or out of the region must be established. As noted previously, data from EPA (1997) indicates that 62 percent of moves are within the same county, 18.5 percent of moves are to a different county within the same state, and the remaining moves are out of the state.

For this evaluation, six different starting ages were examined: age 0 years (i.e., born into region), 10 years, 20 years, 30 years, 40 years and 50 years. Also, two different distributions for moves were utilized. The first distribution assumed that all moves within the same county and 20% of the moves to a different county within the same state were within the region. All other moves were outside the region. In other words, 65.7% of moves are within the region and 34.3% of moves are out of the region. The second distribution assumed that all moves within the same county and 50% of the moves to a different county within the same state were within the region and all other moves were outside the region. In other words, 71.3% of moves are within the region and 28.7% of moves are out of the region.

Table 2-8 shows the result of simulating the time spent within the region for twenty individuals assuming the starting age is 0 years, 71.3% of moves are within the region and the lifetime is 75 years (the years in the region cannot exceed 75 years). In Table 2-8, the first column is the number identifying the individual. The next 20 columns represents the time in each residence. If the value is zero, it is assumed the individual moved out of the region in a previous move. The last column is the total number of years in the region. This is calculated by summing the years in a residence and capping this number by the years in a lifetime (75 years). This process was simulated for 5000 individuals and the results were used to develop a distribution of time spent in the region.

This distribution depends on two inputs, the age of the individual when he or she enter the region and the probability that a move will be within the region. Table 2-9 presents the mean and 95th percentile of time spent within the region depending on the start age and the percentage of moves that are within the region.

For the evaluation of exposure to an angler, the cumulative distribution presented in Table 2-6 was used. This cumulative distribution is for a person born into the region (start age is 0 years) and 65.7% of moves are within the region.

It should be noted that some uncertainty exists in ED for a variety of reasons. All sport fish consumption surveys are short term, reflecting behavior over a few weeks to a year. There are no long term angler surveys that attempt to quantify sport fish consumption patterns over a long period of time. For the Lower Fox River and Green Bay, the answers to two questions are critical in determining exposure duration.

- To what extent does short term sport fish consumption behavior reflect long term behavior by an angler? Do anglers maintain the same level of fishing and sport-fish consumption over their entire lifetime or does this behavior change? The behavior is certain to change dramatically for some anglers (either increasing or decreasing), but this change is not characterized in any long-term angler survey. Thus, this is a significant source of uncertainty.

- How many years does an angler catch fish from the Lower Fox River and Green Bay? This question can be restated in a way that relates to the previous question: How many years can short term behavior be used to predict long term behavior? As discussed previously, the answer to this question is subject to significant uncertainty. Exponent (2000) used angler survey data from the Lower Fox River to develop a distribution for ED using a methodology developed by Price et al. (1998). ThermoRetec (2000) took a different approach to estimating ED, assuming that the number of years an angler fishes from the Lower Fox River and Green Bay depends on the number of years an individual lives in the Lower Fox River and Green Bay region.

The probability distribution for ED used by ThermoRetec (Table 2-6) is representative only of variability in exposure duration among different anglers. As discussed above, there is considerable uncertainty in this estimate of variability and the results presented in Table 2-9 are reflective of this uncertainty.

2.3.6 Body Weight (BW)

The parameter BW represents the body weight of potential receptors. This parameter varies within the angling population. The distribution of body weight of the general population of the United States has been fairly well characterized, and, assuming the distribution of body weight for the angling population is similar to the general population of the United States, the distribution of body weight for

the angling population is well characterized. Because this parameter has been extensively studied, there is no significant uncertainty associated with the distribution of body weight. According to EPA (1997), the mean body weights for males of all races between the ages of 18 and 74 years is 78.1 kg, with a standard deviation of 13.5 kg. The mean body weights for females of all races between the ages of 18 and 74 years is 65.4 kg with a standard deviation of 14.6 kg.

ThermoRetec assumed that the distributions of body weights for males and females between the ages of 18 and 74 are truncated normal, with the above referenced means and standard deviations. For males, the body weight was truncated between a minimum of 40 kg and a maximum of 200 kg. For females, the body weight was truncated between a minimum of 35 kg and a maximum of 150 kg. The distribution of the body weight of the angling population was determined by adding up the probability distributions for males and females between 18 and 74 years of age with equal weight (i.e., 50% each).

Selected statistical measures of the distribution thus obtained are presented in Table 2-10. This table shows that the mean body weight for the potentially exposed population is 72.1 kg, and the 5% and 95% percentiles are 56.8 kg and 88.2 kg, respectively. In their evaluation Exponent (2000) used a fixed body weight of 70 kg.

2.3.7 Averaging Time (ATc and ATnc)

The averaging time for estimating the daily intake averaged over a lifetime, (ATc) is used in the calculation of cancer risks. Exponent (2000) used 70 years, while ThermoRetec (2000) used 75 years (EPA, 1997).

The averaging time for estimating the daily intake averaged over the exposure period (ATnc) is used in the calculation of noncancer hazard indices. The exposure period is equal to the exposure duration (converted from years to days) in this evaluation.

2.4 Distributions for Fish Intake Rate and Exposure Frequency (IR and EF)

This subsection discusses the distributions for fish ingestion rate (grams of fish consumed per meal or per day) and exposure frequency (meals per year or days per year) used in this analysis. Estimates of these distributions were obtained from the following studies:

- Recreational Angler
  - West et al. (1989);
  - West et al (1993);
  - Fiore et al. (1989); and
  - Exponent (2000).

- High Intake Fish Consumers
  - low income minorities from West et al. (1993);
  - Hmong for all fishing sources from Hutchison and Kraft (1994) and Hutchinson(1994); and
  - Hmong for the Lower Fox River only from Hutchison (1999).

The following subsections discuss the data presented in each of these studies and the assumptions used by ThermoRetec and Exponent (2000).

2.4.1 Recreational Anglers

West (1989)

EPA (1997) presents distributional data derived from the West et al. (1989) study. IR is presented as a probability distribution of the average daily ingestion rate (in g/day) over the course of a year. As such, EF is taken as 365 days. West et al. (1989) provide data on the quantity of fish consumed by only those anglers who eat sport caught fish and indicate that 16% of all the anglers surveyed did not eat any fish. The probability distribution of fish intake rate is calculated by multiplying the distribution of all anglers that eat sport-caught fish by the distribution of fish intake rate for the anglers who eat such fish. The data included in the distributions used for these calculations and the statistics of the resulting ingestion rate distribution are presented in Table 2-11.

West et al. (1993)

SAIC (1995) developed a probability distribution for the annualized intake rate (g/day) for all anglers in the West et al. (1993) study. This distribution is presented in Table 2-12. EF is taken as 365 days.

Fiore et al. (1989)

EPA (1997) presents distributional data on the number of meals per year for Wisconsin anglers who eat fish based on the study by Fiore et al. (1989). It should be noted that, based on a conversation with Jackie Moya of the EPA, the percentile data presented in Table 10-70 of EPA (1997) refers to the population of anglers who eat fish. In contrast, the mean annual number of sport caught meals presented in that table (18 meals) refers to the whole population of anglers. It is stated in EPA (1997) that 91% of the angler population eat sport caught fish.

As such, for 9% of the angler population, the intake rate is zero. The exposure frequency distribution for all anglers is obtained by multiplying the exposure frequency distribution for sport anglers who eat fish by the distribution of recreational anglers who eat such fish. It should also be noted that, in order for the mean number of meals for all recreational anglers to match the reported value of 18 meals/year, it was necessary to set the maximum number of meals to 140 per year, rather than the 365 meals/year presented in Table 10-70 of EPA (1997). The 365 meals per year is interpreted as the maximum theoretical yearly number of meals. These distributions are presented in Table 2-13 along with the statistics of the resulting distribution for EF. The fish ingestion rate (IR) is taken as 227 g/meal.

Exponent (2000)

Exponent (2000) estimated the fish intake rate (IR) and exposure frequency (EF) based on an angler survey of the Lower Fox River conducted by Triangle Economic Research, Inc. Tables 2-14 and 2-15 present the parameters for these two distributions.

It should be noted that this survey data was not adjusted to account for the influence of fish advisories on angler behavior. The survey by Hutchison (1999) indicated that anglers who fish from the Lower Fox River have altered their behavior based on fish advisories. Thus, the Exponent (2000) distribution for EF represents a lower bound estimate of fish ingestion rates for the scenario where there are no fish advisories.

2.4.2 High Intake Fish Consumers

West et al. (1993)

SAIC (1995) developed a cumulative distribution for the annualized intake rate for low income minority anglers in the West et al. (1993) study. This distribution is presented in Table 2-16. EF is taken as 365 days/year.

Hutchison (1994) and Hutchison and Kraft (1994)

Hutchison and Kraft (1994) provide distributional data on the number of meals of sport-caught fish consumed by Hmong anglers from all fishing locations. This information is presented in Table 2-17. Hutchison and Kraft (1994) did not quantify the meal size, but Hutchison (1994), in a study of Hmong anglers in the Sheboygan, Wisconsin area, developed distributional data on meal size. This distributional data is presented in Table 2-18.

Hutchison (1999)

Hutchison (1999) provides distributional data on the number of meals of sport-caught fish consumed by Hmong/Laotian anglers from the Lower Fox River in the city of Green Bay. This distributional data is presented in Table 2-19. No information is presented in Hutchison (1999) on meal size. The meal size was taken as 227 g/meal in the analysis presented in this appendix.

Hutchison (1999) surveyed anglers who fish from the Lower Fox River and determined the amount of fish they consume from the Lower Fox River. Hutchison (1999) also asked anglers if they were aware of the fish advisories on the river and if their fishing behavior had been modified by these advisories. Many anglers indicated that they were aware of the fish advisories and that their behavior had been modified. The results of the Hutchison (1999) survey presented in Table 2-19 have not been adjusted to account for the influence of the fish advisories. Thus, the distribution in Table 2-19 for EF represents a lower bound estimate of fish ingestion rates for the scenario where there are no fish advisories.

2.4.3 Evaluation of Uncertainty and Variability

As discussed above, different studies produced different results for the distributions of IR and EF, and, therefore, for the distribution of the product IR*EF (g/year), which represents the grams of fish ingested by anglers over the course of a year. Each distribution is representative of variability associated with IR and EF.

The fact that different distributions were obtained by different researchers, however, is representative of the fact that, in addition to variability, uncertainty is also associated with the estimation of the quantity IR*EF. Consistent with draft EPA guidance (EPA, 1999), separate risk calculations are performed in Section 4 of this appendix, based on each of the studies discussed in Sections 2.4.1 and 2.4.2. The results of these separate calculations are then used to provide a quantitative estimate of the confidence of the estimates of risks and hazard indices (Section 4).

3 Comparison of Exponent Assumptions and ThermoRetec Assumptions

This section presents a comparison of the assumptions used in the evaluation of risks and hazard indices in Exponent (2000) and the focused evaluation presented in the main report. To make the comparison more clear, and eliminate the influence of the assumptions used for fish concentrations, unit risks and unit hazard indices are calculated and compared. Unit risks and unit hazard indices are the risk and hazard index associated with a concentration of 1 mg/kg PCBs in fish.

Risks and hazard indices were calculated in the main report for a Reasonable Maximum Exposure (RME) scenario and Central Tendency Exposure (CTE) scenario for the four reaches of the Lower Fox River and three zones within Green Bay. Different values of risk and hazard index were calculated based on different assumptions regarding intake parameters and concentrations of PCBs in fish. Exponent (2000) used a probabilistic approach to calculate probability distributions of risks and hazard indices over the whole Lower Fox River, independent of the stretch.

High intake fish consumers represent subpopulations of the recreational angler population that are more highly exposed than the general population of recreational anglers. In the main text, ThermoRetec identified three such subpopulations: low-income minorities, Native Americans and Hmong. Exponent (2000) argued that these subpopulations did not eat significantly more fish from the Lower Fox River and Green Bay, so Exponent (2000) did not evaluate exposures and health effects for any subpopulations. Since Exponent (2000) did not explicitly evaluate exposures to high intake fish consumers, a comparison of ThermoRetec and Exponent (2000) results with respect to high intake fish consumers cannot be performed.

The two risk assessments provide different outputs [point value estimates of risks and HIs for RME and CTE scenarios in the main report, and probability distributions of risk and hazard index for Exponent (2000)]. As such, the results of the two risk assessments are not directly comparable. To better understand the fundamental similarities and differences between the two approaches, RME and CTE values were developed from the Exponent (2000) distributions for each intake parameter and unit risks and unit hazard indices were calculated for the RME and CTE scenarios.

Table 3-1 summarizes the intake assumptions and toxicological parameters used in this analysis. Intake assumptions are provided in Table 3-1 for the two studies of Michigan anglers by West et al. (1989) and West et al. (1993); the average of the two West et al. Studies; the study of Wisconsin anglers by Fiore et al. (1989); and the study by Exponent (2000). The values for each parameters in Table 3-1 are the same across the studies with the following exceptions: daily intake rate of fish (IR), exposure frequency (EF), exposure duration (EP) and body weight (BW). The basis for ThermoRetec's assumptions are provided in Sections 5.3 and 5.9 of the main text.

As discussed in Section 2.3.2 of this appendix, this appendix discusses studies that use different approaches to estimate the annual fish intake rate for recreational anglers (i.e., the product IR*EF in g/year). To facilitate the comparison of the fish intake assumptions in the various studies, the annual fish consumption rates were calculated using two common bases. For the first basis, the annual quantity of fish consumed is calculated and divided by 365 days to yield an annualized daily average for IR. This basis is termed Annualized IR in Table 3-1 and EF is constant at 365 days per year. For the second basis, the annual quantity of fish consumed is calculated and divided by an average meal size of 227 g/meal to yield the number of meals of fish per year for EF. This basis is termed Normalized Meals per Year in Table 3-1 and IR is constant at 227 g/meal. This comparison is presented at the bottom of Table 3-1.

The values of IR and EF provided in Table 3-1 for Exponent (2000) were determined as follows. Exponent provides distribution for both IR and EF. These distributions were numerically multiplied together (using Monte Carlo techniques) to yield the distribution of the annual rate of fish consumption and then divided by 365 to give the distribution of the annual rate of fish consumption on a daily basis. The mean of this distribution was selected for the CTE scenario and the 95% value was selected for the RME scenario.

The values for ED provided in Table 3-1 for Exponent (2000) were determined similarly. Exponent (2000) provides a distribution for ED. The mean for this distribution was selected for the CTE scenario and the 95% value was selected for the RME scenario.

The body weights used by ThermoRetec, 71.8 kg, and Exponent (2000), 70 kg, differ, but the differences are so slight that it was a negligible effect on the calculated unit risks and HIs.

In Table 3-1, the reduction factor (RF) is the same for all studies and scenarios, even though the RF developed by Exponent (2000) differs from the RF developed by ThermoRetec.

In their analysis, Exponent (2000) assigned a distribution to the reduction factor (RF). Their reduction factor is based on the overall reduction in mass of PCBs that would be consumed as a result of cooking fish fillets. Exponent used only fillet without skin data in estimating the fish concentration. In the main text, ThermoRetec used mostly skin on fillet data along with some fillet data to estimate their fish concentrations. There is greater reduction in PCB mass associated with the use of skin on fillet data-reduction from trimming as well as cooking. Therefore, to make a more accurate comparison of Exponent's (2000) assumptions to ThermoRetec's assumptions, the ThermoRetec reduction factor of 0.5 was used in the calculations with Exponent (2000) assumptions.

Table 3-1 provides the calculated unit risks and unit hazard indices using ThermoRetec's and Exponent's (2000) assumptions. Unit risks and unit hazard indices are the cancer risks and hazard indices for a total PCB concentration of 1 mg/kg in fish. The highest unit risk and unit hazard index are calculated using the RME and CTE assumptions from West et al. (1993). Table 3-1 also presents the ratio of each unit risk to the unit risk for West et al. (1993) and the ratio of each unit hazard index to the unit hazard index for West et al. 1993. Figure 3-1 plots the unit risks and Figure 3-2 plots the unit hazard indices.

The RME assumptions from West et al. (1989) produced the second highest unit risk and unit hazard index [at 50% of the values using West et al. (1993)]. Similarly, the RME assumptions from Fiore et al. (1989) resulted in unit risk and unit hazard index values of 47.8% of the value using West et al. (1993). The unit risk and unit hazard index calculated using the RME assumptions from the Exponent(2000) evaluation were 22% of the values using West et al. (1993). While these are the lowest values in the evaluation, they are comparable to the values used by West et al. (1989) and Fiore et al. (1989).

For the CTE scenario, the unit risk and unit hazard index values for West et al. (1989) and Fiore et al. (1989) are 71% and 66% of the values for West et al. (1993). The Exponent (2000) unit risk value is 15% of the CTE value from West et al. (1993). The unit hazard index is 28% of the value for West et al. (1993). These values are lower than the values from Fiore et al. (1989). These lower values are mostly due to a lower value for exposure duration (15 years) used by Exponent (2000) as compared to the value of 30 years used by ThermoRetec.

In conclusion, a comparison of intake assumptions used by Exponent (2000) and ThermoRetec (in the main report) indicates that Exponent (2000) intake assumptions result in a generally lower unit risk and unit hazard index than the assumptions used by ThermoRetec. The difference between the unit risks and unit hazard indices calculated by Exponent (2000) and ThermoRetec depends on the study used to estimate fish intake assumptions. This difference is generally greatest for the West et al. (1993) study and least for the Fiore et al. (1989) study.

4 Probabilistic Evaluation of Exposure to PCBs in Fish

This section presents the results of probabilistic calculations for cancer risks and hazard indices for three data sets characterizing PCB concentrations in fish. These data sets are the Exponent (2000) distribution of PCB concentrations in fish for the entire Lower Fox River, the distribution of PCB concentrations in the Little Lake Butte des Morts reach and the distribution of PCB concentrations in the De Pere to Green Bay reach.

4.1 Results Using Fish Concentration Distribution from Exponent (2000)

Table 4-1 summarizes the intake assumptions used for the recreational anglers utilizing the fish concentration data from Exponent (2000). Four separate calculations were performed, based on different intake assumptions. Table 4-2 presents the cancer risk and hazard index distributions resulting from the probabilistic calculations, as well as the CTE and RME values calculated using intake parameters for the CTE and RME scenarios and the mean concentration for the distribution of PCB concentrations in fish from Exponent (2000). Figures 4-1 through 4-4 provide the cumulative distributions for cancer risks and also show the mean cancer risk from the simulation as well as the cancer risks based on CTE and RME assumptions. Figures 4-5 through 4-8 provide analogous information on the distribution of hazard indices. In general, the mean of the risk and hazard indices probability distributions and CTE risks and hazard indices are very similar. The RME risks and hazard indices occur within the 85^{th} to 99^{th} percentiles, with most between the 90^{th} and 95^{th} percentiles.

Table 4-3 summarizes the intake assumptions used for the high intake fish consumers utilizing the fish concentration data from Exponent (2000). Three separate calculations were performed, based on the different intake assumptions. Table 4-4 presents the cancer risk and hazard index distributions resulting from the probabilistic calculations. Figures 4-9 through 4-11 provide the cumulative distributions for cancer risks, while Figures 4-12 through 4-14 provide analogous information on the distribution of hazard indices. In general, the mean of the risk and hazard indices probability distributions and CTE risks and hazard indices are very similar. The RME risks and hazard indices occur within the 90^{th} to 98^{th} percentiles, with most between the 90^{th} and 95^{th} percentiles.

4.2 Results Using Fish Concentration Distribution for the Little Lake Butte des Morts Reach

Table 4-5 summarizes the intake assumptions used for the recreational anglers utilizing the fish concentration data from Little Lake Butte des Morts. Four separate calculations were performed, based on different intake assumptions. Table 4-6 presents the cancer risk and hazard index distributions resulting from the probabilistic calculations. Figures 4-15 through 4-19 provide the cumulative distributions for cancer risks and Figures 4-19 through 4-22 provide analogous information on the distribution of hazard indices. In general, the mean and CTE risks and hazard indices are very similar. The RME risks and hazard indices occur within the 90th to 99th percentiles, with most between the 94th and 98th percentiles.

Table 4-7 summarizes the intake assumptions used for the high intake fish consumers utilizing the fish concentration data from Little Lake Butte des Morts. Three separate calculations were performed, based on different intake assumptions. Table 4-8 presents the cancer risk and hazard index distributions resulting from the probabilistic calculations. Figures 4-23 through 4-25 provide the cumulative distributions for cancer risks and Figures 4-26 through 4-28 provide analogous information on the distribution of hazard indices. In general, the mean of the risk and hazard index probability distributions and CTE risks and hazard indices are very similar. The RME risks and hazard indices occur within the 90th to 98th percentiles, with most between the 90th and 95th percentiles.

4.3 Results Using Fish Concentration Distribution for the De Pere to Green Bay Reach

Table 4-9 summarizes the intake assumptions used for the recreational anglers utilizing the fish concentration data from the De Pere to Green Bay. Four separate calculations were performed, based on different intake assumptions. Table 4-10 presents the cancer risk and hazard index distributions resulting from the probabilistic calculations. Figures 4-29 through 4-32 provide the cumulative distributions for cancer risks and Figures 4-33 through 4-36 provide analogous information on the distribution of hazard indices. In general, the mean and CTE risks and hazard indices are very similar. The RME risks and hazard indices occur within the 90th to 99th percentiles, with most between the 94th and 98th percentiles.

Table 4-11 summarizes the intake assumptions used for the high intake fish consumers utilizing the fish concentration data from the De Pere to Green Bay. Three separate calculations were performed, based on different intake

assumptions. Table 4-12 presents the cancer risk and hazard index distributions resulting from the probabilistic calculations. Figures 4-37 through 4-39 provide the cumulative distributions for cancer risks and Figures 4-40 through 4-42 provide similar information on the distribution of hazard indices. In general, the mean of the risk and hazard index probability distributions and CTE risks and hazard indices are very similar. The RME risks and hazard indices occur within the 94th to 98th percentiles, with most between the 95th and 98th percentiles.

4.4 Comparison of Probabilistic Results with CTE and RME Values

As pointed out in Sections 4.1 through 4.3, the CTE and RME values of risk and hazard indes calculated in the main report are generally close to the mean and 95% values of the respective probability distributions. This is consistent with the interpretation provided in EPA (1999) of the RME value as corresponding to the 90th to 99th percentile of the risk and hazard indices distributions, and being representative of the high-end range of risk and hazard index. Figures 4-43 through 4-48 present an explicit comparison of CTE and RME values with the probability distribution data. These figures provide a visual means for evaluating the position of the CTE and RME values with respect to the probability distribution generated in the probabilistic analysis, and confirm the observations provided in Sections 4.1 through 4-3 that the CTE values generally correspond to the means of the distributions, and the RME values are generally at the high end (90th to 99th percentiles).

4.5 Interpretation of Results

Probabilistic calculations of risk and hazard index were performed in this appendix for the following cases:

- Entire Fox River
  - Recreational Anglers
    - West et al., 1989
    - West et al., 1993
    - Fiore et al., 1989
    - Exponent, 2000

  - High Intake Fish Consumers
    - Low Income Minorities, West et al., 1993
    - Hmong, Hutchison, 1994 and Hutchison & Kraft, 1994
    - Hmong/Laotians, Hutchison, 1999

- Little Lake Butte des Morts Reach
  - Recreational Anglers
    - West et al., 1989
    - West et al., 1993
    - Fiore et al., 1989
    - Exponent, 2000

  - High Intake Fish Consumers
    - Low Income Minorities, West, et al., 1993
    - Hmong, Hutchison, 1994 and Hutchison & Kraft, 1994
    - Hmong/Laotian, Hutchison, 1999

- De Pere to Green Bay Reach
  - Recreational Anglers
    - West et al., 1989
    - West et al., 1993
    - Fiore et al., 1989
    - Exponent, 2000

  - High Intake Fish Consumers
    - Low Income Minorities, West, et al., 1993
    - Hmong, Hutchison, 1994 and Hutchison & Kraft, 1994
    - Hmong/Laotian, Hutchison, 1999

As discussed in Section 2, for each of the above cases, some of the parameters relevant to the calculation of risk and hazard index are characterized by variability. As such, the calculated risks and hazard indices reflect variability in exposure and are specified as probability distributions rather than single values. These probability distributions of risk and hazard indices are presented in Tables 4-2, 4-4, 4-6, 4-8 and 4-10. These distributions do not reflect uncertainty in the input parameters. In the terminology used in the draft EPA guidance on probabilistic risk assessment (EPA, 1999), these distributions are the result of a one-dimensional probabilistic risk analysis.

The above referenced tables (and associated figures showing cumulative risks and hazard index distributions) explicitly provide the probability of a specific risk or hazard index for an individual from the exposed population based on a set of assumptions. For example, from Table 4-6, it can be seen that based on the assumptions presented in West et al. (1989) for a recreational angler, there is a 50% probability that an angler has a cancer risk less than or equal to 2.7×10^{-5}, and has an associated noncancer hazard index of less than or equal to 2.8. Similarly, using the same probability distribution, there is a 95% probability that the same

recreational angler has a cancer risk less than or equal to $3.1x10^{-4}$, has an associated noncancer hazard index of 13. All columns in Tables 4-2, 4-4, 4-6, 4-8 and 4-10 can be read in the same way.

Tables 4-2, 4-4, 4-6, 4-8 and 4-10 (and associated figures showing cumulative risk and hazard index distributions) can also be used to answer the question *what is the probability that the risk or hazard index for an exposed individual will exceed a specified level?* Using again the data in Table 4-6, based on the West et al. (1989) intake assumptions there is a probability between 20% and 25% that the risk to an exposed angler is less than or equal to $1x10^{-6}$. Also, there is a probability of just over 35% that the risk exceeds $1x10^{-5}$. Conversely, there is a greater than 75% probability that the risk is less than or equal to $1x10^{-4}$. This means that there is a less then 25% probability that the risk exceeds $1x10^{-4}$. All columns in Tables 4-2, 4-4, 4-6, 4-8 and 4-10 can be read in the same way.

4.6 Evaluation of Uncertainty

As previously indicated, the probability distributions discussed above do not reflect the fact that uncertainty is associated with some of the input exposure parameters. For example, there is uncertainty in the assumptions used to estimate fish intake rates for recreational anglers and high intake fish consumers. This is reflected in the fact that, as discussed in Section 2.4, different studies provide different probability distributions for the ingestion rate (IR) and the exposure frequency (EF) for the same populations (recreational anglers and high intake fish consumers). In this subsection, a procedure consistent with draft EPA guidance for probabilistic risk assessment (EPA, 1999) is used to estimate the uncertainty associated with the risk and hazard index calculations for recreational anglers and high intake fish consumers in the three portions of the Fox River considered [whole river (Exponent, 2000), Little Lake Butte des Morts reach, and De Pere to Green Bay reach].

Figure 4-49 and 4-50 show the cumulative probability distributions of risk and hazard index to recreational anglers, based on the Exponent (2000) fish concentration distribution for the whole river. The results for the four set of studies used (reflecting four different set of intake assumptions) are shown on the same graph. It should be noted that the assumptions for IR and EF are the only differences among the four curves shown. Figures 4-51 and 4-52 show the probability distributions for high intake fish consumers, based on the three studies (and intake assumptions) used. Figures 4-53 through 4-60 present analogous information for the Little Lake Butte des Morts reach and De Pere to Green Bay reach.

It should be noted that the three studies used of anglers to evaluate high intake fish consumers do not evaluate the same populations, although they are still

representative of the same category of anglers. The low income minority anglers surveyed by West et al. (1993) probably include very few Hmong or Laotians. The fishing behavior of Hmongs characterized by Hutchison and Kraft (1994) is for all fishing, while the fishing behavior of Hmongs and Laotions characterized by Hutchison (1999) is for fishing only from the Lower Fox River in the city of Green Bay. Thus, the results presented in Figures 4-51 and 4-52, 4-55 and 4-56, and 4-59 and 4-60 should be interpreted with these distinctions in mind.

Inspection of these figures reveals that different values of risk (and hazard index) are calculated, based on each study, for a given percentile. For example, based on Figure 4-49, the 90% risk value ranges between less than 10^{-5} based on Exponent (2000), and about than 10^{-4} based on West et al. (1993). Similarly the 50% risk value ranges between less than $2x10^{-6}$ based on Exponent (2000) and $1x10^{-5}$ based on West et al. (1989).

Thus, for each percentile value of risk and hazard index, a range (rather than a single value) was estimated, reflecting the fact that there is uncertainty in the exposure assumptions. Figures 4-61 through 4-72 present a graphical evaluation of the uncertainty in the variability statistics in a format consistent with the format recommended in EPA (1999). In these figures, the calculated range for the mean and selected percentiles is plotted on the vertical axis for the three portions of the river evaluated, and for the two receptor categories (recreational anglers and high intake fish consumers). The data presented in Figures 4-61 through 4-72 is summarized in Tables 4-13 through 4-15.

The following should be noted.

- In Figures 4-61 through 4-72, some of the lower percentile values have a risk and HI of zero (this is due to the fact that under some of the assumptions, some percent of the potentially exposed population does not eat fish, and therefore is not exposed to PCBs through the fish ingestion pathway). Since the risk data is plotted on a logarithmic vertical scale, a value of zero cannot be plotted. In these cases, a value of 1E-08, corresponding to the lowest value included on the vertical axis is plotted. This problem does not arise for the plots of hazard index, as the vertical scale is linear in these plots.

- For each percentile value, average risks and hazard indices are calculated, representing the arithmetic average of the values for each study utilized (four values for the recreational angler, and three values for the high intake fish consumer). This means, essentially, that each study is assigned the same weight in the uncertainty evaluation. A

more detailed statistical evaluation of the data used to generate the probability distribution excerpted for each study might indicate that non-uniform weights could be assigned to the data generated in the studies. However, such statistical evaluation is beyond the scope of the analysis presented in this appendix. As such, the equal weight assumption is used in this evaluation.

The information presented in Figures 4-61 through 4-72 and Tables 4-13 through 4-15 can be used to provide a quantitative estimate of each percentile value for risk and HI, and of the confidence in the estimate. For example, Based on the data presented in Table 4-14, the best estimate of the mean value of risk to recreational anglers in the Little Lake Butte des Morts reach is 6.5×10^{-5}. However, this value could be as low as 1.4×10^{-5}, and as high as 10^{-4}. The additional data in Figures 4-61 through 4-72 and Tables 4-13 through 4-15 can be interpreted in the same manner. The data presented in these tables and figiures show that the uncertainty in the estimate of the probability distributions of risk and hazard indices is moderate, as reflected by the fact that the minimum and maximum values for the selected statistical parameters are generally within a factor of 10 of each other.

4.7 Sensitivity Analysis

A qualitative sensitivity analysis was performed to understand how the variability in the various input parameters specified as probability distributions affects the calculated variability of risk and hazard index The starting point for this analysis are the equations used for risk and hazard index, which were discussed in Section 2.1, and are reproduced below (all variables have been previously defined).

Risk is calculated according to the following equation:

$$R = Cfish \cdot IntFacC \cdot CSFo$$

where *IntfacC* represents the intake factor for cancer risk [$(mg/kg)^{-1}$], given by:

$$IntFacC = \frac{IR \cdot RF \cdot ABS \cdot CF \cdot EF \cdot ED}{BW \cdot ATc}$$

Combining the two equations yields the following expression for risk:

$$R = Cfish \cdot \frac{IR \cdot RF \cdot ABS \cdot CF \cdot EF \cdot ED}{BW \cdot ATc} \cdot CSFo$$

Similarly, the expression for hazard index is:

$$HI = Cfish \cdot \frac{IR \cdot RF \cdot ABS \cdot CF \cdot EF \cdot ED}{BW \cdot ATnc \cdot RfDo}$$

Using basic concepts from calculus, small variations in risk can be written (Young, 1968):

$$\frac{\Delta R}{R} = \frac{\Delta Cfish}{Cfish} + \frac{\Delta IR}{IR} + \frac{\Delta RF}{RF} + \frac{\Delta ABS}{ABS} + \frac{\Delta CF}{CF} + \frac{\Delta EF}{EF} + \frac{\Delta ED}{ED} + \frac{\Delta BW}{BW} + \frac{\Delta AT_c}{AT_c} + \frac{\Delta C}{C}$$

Where ΔR represents a small variation in risk, ΔIR a represents small variation in daily fish ingestion rate, and similarly for all other variables. An analogous expression can be written for ΔHI, but this is not done here to simplify the discussion, and the following discussion is restricted to risk. The results for risk can be easily extended to hazard index the calculation of hazard index.

To understand qualitatively how variations in each parameter on the right hand side of the equation above affect relative variations in the magnitude of risk, the following approximations is made: $\Delta IR \sim \sigma_{IR}$, where σ_{IR} represents the standard deviation of the probability distribution of IR (the fish ingestion rate). In addition, the mean value is taken as representative of each variable. Analogous approximations are made for all other variables entering the calculation of risk. Using these approximations, the relative variation in the magnitude of risk can be written as:

$$\frac{\Delta R}{R} \approx \frac{\sigma_{Cfish}}{Cfish} + \frac{\sigma_{IR}}{IR} + \frac{\sigma_{RF}}{RF} + \frac{\sigma_{ED}}{ED} + \frac{\sigma_{BW}}{BW}$$

Similarly, it can be shown that the relative variation of HI can be written as:

$$\frac{\Delta HI}{HI} \approx \frac{\sigma_{Cfish}}{Cfish} + \frac{\sigma_{IR}}{IR} + \frac{\sigma_{RF}}{RF} + \frac{\sigma_{BW}}{BW}$$

It should be noted that in the risk and HI equations *CF, ABS, ATc, EF* and *CSFo* are taken as point values (i.e., their standard deviation is zero); as such their standard deviation is zero, and their respective terms disappear from the equations. In addition, the terms associated with ED and AT_{NC} disappear from the hazard index equation above because they are taken to be equal, and therefore cancel out.

The above equations provides qualitative tools to evaluate the effect of variability of each input variable on the resulting calculated risk and HI. Inspection of these equations reveals that the variables with the greatest effect on the variability of risk and hazard index are the ones with the greatest relative variability, i.e., those whose relative standard deviation (i.e., the ratio of standard deviation to mean value) is greatest.

Tables 4-16 and 4-17 present an explicit evaluation of the relative effect of each variable in the calculations of risk and HI for recreational anglers and high intake fish consumers for two selected studies for the Little Lake Butte des Morts reach. Analysis of the other studies would yield qualitatively similar results.

The results presented in Table 4-16 indicate that the variability in the risk calculations is mostly due to the variability of two parameters, namely IR (g/day), the fish ingestion rate, and ED (years), the exposure duration. Variability in all other parameters is essentially negligible. Similarly, Table 4-17 indicates that the variability in hazard index is due essentially in its entirety to the variability in IR. In addition, a comparison of the relative standard deviations for the calculated risks and hazard indices with the sum of the relative standard deviations of all variable parameters, indicates that the two quantities are relatively close (based on the analysis discussed above, these quantities should be essentially equal). This indicates that the assumptions used to derive the equations used for the sensitivity analysis are reasonable ones.

4.8 Conclusions

A probabilistic risk assessment of exposure to PCBs in fish was performed, and is documented in Section 4. Consistent with EPA guidance (EPA, 1999), the probabilistic risk assessment included an evaluation of both variability and uncertainty. The most significant findings of the focused probabilistic risk assessment are as follows.

- The deterministic CTE estimates of risk and hazard index provided in the main report are generally close to the means of the respective probability distributions of risk and hazard index. This is consistent

with the interpretation of the CTE as the average risk or hazard index for the exposed population.

- The deterministic RME estimates of risk and hazard index provided in the main report are generally in the range of the 90th to 95th percentiles of the respective and HI probability distributions of risk and hazard index. This is consistent with the interpretation provided in EPA (1999) of the RME as a plausible high end risk or hazard index for the exposed population.

- The uncertainty in the estimate of the probability distributions of risk and hazard index due to uncertainty in the fish ingestion rate is moderate, and the minimum and maximum values of selected statistical parameters are generally within a factor of 10 of each other.

5 References

Anderson, H. A., J. F. Amrhein, P. Shubat, J. Hesse, 1993. Protocol for a uniform Great Lakes sport fish consumption advisory. Prepared for the Great Lakes Sport Fish Advisory Task. September.

DeGroot, M., 1975. *Probability and Statistics*. Addison-Wesley Publishing Company, Menlo Park, CA.

EPA, 1997. *Exposure Factors Handbook (Update to Exposure Factors Handbook - May 1989).* EPA/600/8-89/043. Office of Research and Development, Washington, D.C.

EPA, 1999. *Risk Assessment Guidance for Superfund. Volumes 3 - (Part A, Process for Conducting Probabilistic Risk Assessment).* Draft, Revision No. 5, December 1999.

Exponent, Inc., 1999. Baseline Human Health Risk Assessment of PCBs in the Lower Fox River System, prepared for the Fox River Group, April, 1999.

Fire, B.J., H.A. Anderson, L.P. Hanrahan, L.J. Olson, W.C. Sonzogni, 1989. Sport fish consumption and body burden levels of chlorinated hydrocarbons: A study of Wisconsin anglers. *Arch. Env. Health* 44(2): 82-88.

Hutchinson, R., 1994. *Fish Consumption by Hmong Households in Sheboygan, Wisconsin.* Prepared for Tecumseh Products Company, Sheboygan Falls, Wisconsin. September.

Hutchinson, R. and C. E. Kraft, 1994. Hmong Fishing Activity and Fish Consumption. *J. Great Lakes Res.* 20(2):471–478.

Hutchinson, R., 1999. Impact of PCB Contamination on Subsistence Fishing in the Lower Fox River, prepared for Stratus Consulting, Inc. on behalf of U.S. Fish and Wildlife Service.

Price, P.S., P.K. Scott, N.D. Wilson and D.J. Paustenbach, 1998. An empirical approach for deriving information on total duration of exposure from information on historical exposure. *Risk Analysis* 18(5):611-619.

SAIC (Science Applications International Corporation), 1995. *Fish Consumption Estimates Based on the 1991-1992 Michigan Sport Anglers Fish Consumption*

Survey. Prepared for the U.S. Environmental Protection Agency, EPA Contract Number 68-C4-0046, Work Assignment 0-4.

West, P.C., J. M. Fly, R. Marans and F. Larkin, 1989. *Michigan Sport Anglers Fish Consumption Survey*. Natural Resources Sociology Research Lab, Technical Report #1.

West, P. C., J. M. Fly, R. Marans, F. Larkin, and D. Rosenblatt, 1993. *1991–92 Michigan Sport Anglers Fish Consumption Study.* Final report to the Michigan Great Lakes Protection Fund, Michigan Department of Natural Resources. May.

Wilson, N.D., N.M. Shear, D.J. Paustenbach and P.S. Price, 1998. The effects of cooking practices on the concentration of DDT and PCB compounds in the edible tissue of fish. *J. Exposure Analysis and Environmental Epidemiology* 8(3):423-436.

Young, H.D., 1968. (*Statistical Treatment of Experimental Data*).

Appendix B2

General Statistics

1.0 Introduction

This appendix provides statistical summaries of concentration data for fish, waterfowl, surface water and sediment. Section 2 provides statistical summaries of data collected from these media. Section 3 presents a statistical summary of total PCB concentrations in sediments based on interpolation of the sediment analytical data onto a grid. Section 4 provides references.

2.0 Statistical Summary of Analytical Data

Tables 1 through 9 present statistical summaries for constituents in Fish, Waterfowl, Unfiltered Surface Water (total surface water), Filtered Surface Water (dissolved surface water), and Sediment respectively. Each table provides statistical information in a particular category for the following five reaches of Fox River, Little Lake Butte des Morts, Appleton to Little Rapids, Little Rapids to De Pere, De Pere to Green Bay, and Green Bay.

A. Sample Counts. In this category, the following statistical information is provided:

- number of samples
- number of detects
- number of nondetects
- percent nondetects

The percent nondetects is calculated as follows (assuming the number of valid samples is greater than zero):

$$PercNonDet = 100 \cdot \frac{NonDet}{NumSamp}$$

where

PercNonDet	=	percent of nondetects
NonDet	=	number of nondetects
NumSamp	=	number of samples

B. Basic Statistics. In this category, the following statistical information is provided:

- minimum detection limit
- maximum detection limit
- minimum detected concentration
- maximum detected concentration

C. General Summary Statistics. This category provides a variety of summary statistics, including:

- average or mean
- standard deviation
- coefficient of variation
- geometric mean
- geometric standard deviation

In calculating all these summary statistics, nondetects are replaced with half the detection limit.

The median is the concentration at the middle of a sorted list of samples. If the number of samples is odd, the median is the concentration of the middle sample. If the number of samples is even, the median is the average of the concentrations of the two samples in the middle of the list.

The average, x_{avg}, is given by:

$$x_{avg} = \frac{\Sigma\, x_i}{n}$$

where

x_i = the value of sample number *i*; and
n = number of samples.

The standard deviation is the sample standard deviation, s, given by:

$$s = \sqrt{\Sigma \frac{(x_{avg} - x_i)^2}{(n - 1)}}$$

The coefficient of variation, CoefVar, is given by:

$$CoefVar = \frac{s}{x_{avg}}$$

The geometric mean and geometric standard deviation are calculated as follows:

- The data is logarithmically transformed using the natural logarithm (ln).

- The average and standard deviation are calculated for the transformed data, $x_{t\text{-}avg}$ and s_t, respectively, using the equations above.
- The geometric mean, x_{gmean}, and geometric standard deviation, s_g, are calculated by transforming back $x_{t\text{-}avg}$ and s_t, as follows:

$$x_{gmean} = e^{x_{t-avg}}$$
$$s_g = e^{s_t}$$

D. Testing of Normality of Data. In this category, the data is tested to determine if it is represented by a normal distribution. One of two tests is employed. If there are 50 samples or less, the Shapiro-Wilk test of normality is utilized (Shapiro and Wilk, 1965). Using the procedures outlined in Gilbert (1987), the data is sorted and manipulated to calculate a W test statistic. This W-statistic was compared to a W value at a 0.05 quantile. The W value at the 0.05 quantile is found by referring to a lookup table (see Table A7 in Appendix A of Gilbert (1987)). If the W-statistic is greater than or equal to the W value, the data is considered to be normally distributed.

If there are more than 50 samples, the D'Agostino test of normality is utilized (D'Agostino, 1971), which is a two tailed statistical test. Using the procedures outlined in Gilbert (1987), the data is sorted and manipulated to calculate the Y test statistic. For a test of normality at the 0.05 level of significance, the Y values at the 0.025 quantile, $Y_{0.025}$, and 0.975 quantile, $Y_{0.975}$, are determined by interpolating from a lookup table (e.g., Table A8 in Appendix A of Gilbert (1987)). The data is considered to be normally distributed if the Y statistic satisfies the following condition:

$$Y_{0.25} \le Y\text{-}statistic \le Y_{0.975}$$

E. Testing of Log-Normality of Data. In this category, the data is tested to determine if it is represented by a log-normal distribution. The data is transformed by taking the natural logarithm of each sample value. The procedures described previously are then applied to the transformed data. If there are 50 samples or less, the Shapiro-Wilk test of normality is used. If there are more than 50 samples, the D'Agostino test of normality is utilized.

F. Source Concentrations. In this category, the source concentration is calculated following USEPA (1992) guidance. First, the 95% upper confidence limit (UCL) on the mean, which depends on the distribution type, is calculated.

For normally distributed data, the 95% UCL on the mean, UCL_{norm}, is calculated with the following equation (USEPA, 1992):

$$UCL_{norm} = x_{avg} + \frac{t \cdot s}{\sqrt{n}}$$

The one tail t-statistic at a 95% level, t, depends on the number of samples, n, and the standard deviation of the log-transformed data, s_t, and comes from Table A2 in Appendix A of Gilbert (1987).

For log-normally distributed data, the 95% UCL on the arithmetic mean, UCL_{ln}, is calculated with the following equation (USEPA, 1992):

$$UCL_{ln} = e^{(x_{t-avg} + 0.5 \cdot s_t^2 + s_t \cdot H/\sqrt{n-1})}$$

The one tail H-statistic at a 95% level, H, depends on the number of samples, n, and the standard deviation of the log-transformed data, s_t, and comes from Table A12 in Appendix A of Gilbert (1987).

The source concentration is established as the 95% UCL on the mean or the maximum detected concentration, whichever is lower (USEPA, 1992). For data which is nonparametric (i.e., neither normally nor log-normally distributed), the source concentration is established as the greater of the two 95% UCLs (one assuming the data is normally distributed, the other assuming the data is lognormally distributed). If the higher of the two 95% UCLs exceeds the maximum detected concentration, the maximum detected concentration is the source concentration. In this evaluation, if there were more than 15% nondetects, the data was assumed to be nonparametric.

The last two columns in this section provide the adjusted average concentration and the upperbound concentration. The adjusted average concentration was determined as follows. If there were no detects, the adjusted average concentration is ND. If there were detects, the average concentration is the minimum of the average concentration or the maximum detected concentration. All values have units of either mg/kg (for fish, waterfowl and sediment) or mg/L (for surface water). The upperbound concentration was determined with a similar procedure. If there were no detects, the upperbound concentration is ND. If there were detects, the upperbound concentration is the source concentration. All values have units of either mg/kg (for fish, waterfowl and sediment) or mg/L (for surface water).

3.0 Statistical Summary of Interpolated Sediment Data

The analytical results for total PCBs in sediment were compiled, a grid was imposed over each reach of the Lower Fox River and each zone of Green Bay and the analytical data was interpolated to provide a concentration at each point on the grid. The mean and 95% UCL on the mean were determined for each reach and each zone using the data at each grid point. Since there are a large number of grid points for each reach and zone

(at least 9,000) the 95% UCL on the mean was calculated assuming the mean is normally distributed. This is consistent with the Central Limit Theorem of statistics (De Groot, 1975).

In calculating values for each point on the grid, interpolations were made only for grid points where there were analytical data nearby. Grid points outside the area with analytical data were assigned a value of -1 to indicate no data was available at these grid points. Three approaches were utilized for handling these grid points with no data when calculating statistics.

In the first approach, all grid points without data were deleted when calculating statistics. In the second approach, all grid points without data were assigned a concentration of 0.1 ug/kg, which is a nominal detection limit for total PCBs. In the third approach, all grid points without data were assigned a concentration of 0 ug/kg.

Table 10 presents summary statistics for the interpolated total PCB data in surface sediment. This table provides the number of samples, the average, 95% UCL on the average assuming the mean is normally distributed and the maximum. Also presented is the adjusted average concentration which is the average converted from units of ug/kg to units of mg/kg and the upperbound concentration which is the 95% UCL on the mean converted from units of ug/kg to mg/kg.

4.0 References

D'Agostino, B. B., 1971. An Omnibus Test of Normality for Moderate and Large Size Samples, *Biometrika*, 58:341-348.

De Groot, M., 1975. *Probability and Statistics*, Addison-Wesley Publishing Co., Reading, MA.

EPA, 1992. Supplemental Guidance to RAGS: Calculating the Concentration Term. Office of Solid Waste and Emergency Response. Publication 9285.7-C81. May 1992.

Gilbert, R.O., 1987. *Statistical Methods for Environmental Pollution Monitoring*, Van Nostrand Reinhold, New York, New York.

Shapiro, S.S., and M.B. Wilk, 1965. An Analysis of Variance Test for Normality (Complete Samples), *Biometrika*, 52: 591-611.

Appendix B3

Fate and Transport Models and Transfer Factors

1 Introduction

This appendix presents the mathematical models used in the estimation of exposure point concentrations. The following models were used:

- Shower Water to Air Volatilization Model: This model utilizes concentrations in shower water to estimate air concentrations in the bathroom during showering.

- Bath Water to Air Volatilization Model: This model utilizes concentrations in bath water to estimate air concentrations in the bathroom during a bath.

- Surface Water to Air Volatilization Model: This model uses concentrations in surface water to estimate concentrations in outdoor air.

- Sediment to Pore Water Partitioning Model: This model uses concentrations in sediment to estimate concentrations in sediment pore water.

In this analysis, transfer factors were estimated which are the ratio of exposure point concentrations to the source concentrations. These transfer factors can be multiplied by actual source concentrations to produce exposure point concentrations. For the Shower Water to Air Volatilization Model and Bath Water to Air Volatilization Model, the only site-specific data are the water concentrations, so the transfer factors from these models are the same for all areas of interest. For the Surface Water to Air Volatilization Model and Sediment to Pore Water Partitioning Model, the transfer factors use site-specific data, so a separate transfer factor is calculated for each area reach in the Lower Fox River and for Green Bay as a whole.

2 Shower Water to Air Volatilization Model

2.1 Equations

During a shower, chemicals present in shower water are assumed to have the opportunity to volatilize into the air within the shower room. Initially, the concentration of a chemical in the shower room in the air is assumed to be zero. As time goes on, the concentration increases until the shower is finished. At this time, the concentration in the air begins to decrease as air turns over in the room. Figure 2-1 depicts the evolution of the shower room air concentrations over time. The individual taking a shower is assumed to be in the shower room during the shower and for a period after the shower. The relevant exposure point concentration for this individual is the average concentration of the chemical in the air during this exposure event, since the individual is assumed to maintain a constant inhalation rate both during and after the shower.

To estimate this average concentration in the shower room air, the model of Foster and Chrostowski (1987) was used. The model is based on a simple box model of air exchange in the shower room with constant emission of chemicals during the shower. The average concentration in the shower room air is the time weighted sum of the average concentration in the shower room air during the shower and the average concentration in the shower room air after the shower is completed.

$$C_{asav} = \frac{C_{asav1} \cdot T_1 + C_{asav2} \cdot T_2}{T_1 + T_2}$$

where:

C_{asav} = average concentration of chemical in the shower room air (mg/m^3);
C_{asav1} = average concentration of chemical in the shower room air during showering (mg/m^3);
C_{asav2} = average concentration of chemical in the shower room air after showering (mg/m^3);
T_1 = duration of shower (hours); and
T_2 = period individual is in shower room after shower (hours).

Both C_{asav1} and C_{asav2} depend upon the concentration of the chemical in the shower water and this relationship can be expressed through a transfer factor such that the following relationships and transfer factors can be defined:

$$C_{asav1} = TF_{sh1} \cdot C_{ws}$$

$$C_{asav2} = TF_{sh2} \cdot C_{ws}$$

$$C_{asav} = TF_{sh} \cdot C_{ws}$$

$$TF_{sh} = \frac{TF_{sh1} \cdot T_1 + TF_{sh2} \cdot T_2}{T_1 + T_2}$$

where:

C_{ws} = concentration of chemical in the shower water (mg/L);
TF_{sh1} = transfer factor describing relationship between concentration in shower air and shower water during showering (L/m^3);
TF_{sh2} = transfer factor describing relationship between concentration in shower air and shower water after showering (L/m^3); and
TF_{sh} = overall transfer factor describing overall relationship between concentration in shower air and shower water (L/m^3).

The variable TF_{sh1} is determined by first developing an expression for C_{asav1}. This variable is determined by solving the following equation:

$$C_{asav1} = \frac{\int_0^{T_1} C_{as}(t)\ dt}{T_1}$$

where:

$C_{as}(t)$ = concentration of chemical in the shower room air over time (mg/m^3).

The variable $C_{as}(t)$ can be determined by solving the following differential equation:

$$Vsh \cdot \frac{d}{dt} C_{as}(t) = rsh - Qash \cdot C_{as}(t)$$

where:

Vsh = volume of shower room (m^3);
rsh = rate of chemical emission into shower room (mg/hr); and
Qash = rate of air flow out of shower room (m^3/hr).

This equation states that the rate at which the mass of chemical in the shower room changes depends on the difference in the rate at which the chemical is volatilized from the shower water minus the rate at which the chemical leaves the shower room as air circulates through the shower room.

The rate at which the chemical is introduced into the shower room with shower water is the flow rate of the shower water times the concentration of the chemical in the water. Only a fraction of the chemical so introduced is volatilized, however, before the water drains out of the shower. Thus, the rate at which the chemical is introduced into the shower room is given by:

$$rsh = fv \cdot Qwsh \cdot C_{ws}$$

where:

fv = fraction of chemical volatilized; and
Qwsh = shower water flow rate (L/hr).

The differential equation describing the change in C_{as} over time becomes:

$$\frac{d}{dt} C_{as} = \frac{fv \cdot Qwsh}{Vsh} \cdot C_{ws} - \frac{Qash}{Vsh} \cdot C_{as}$$

By defining two rate constants, *ksw* and *ksa*, this equation can be restated:

$$\frac{d}{dt} C_{as} = ksw \cdot C_{ws} - ksa \cdot C_{as}$$

The constants *ksw* and *ksa* are defined as:

$$ksw = \frac{fv \cdot Qwsh}{Vsh}$$

where:

$$ksa = \frac{Qash}{Vsh}$$

ksw = first order rate constant describing release of chemical from shower water to air (L/m^3-hr); and

ksa = first order rate constant describing turnover of air in shower room (1/hr).

The solution to this differential equation is:

$$C_{as}(t) = \left(\frac{ksw}{ksa}\right) C_{ws} \left(1 - e^{-ksa \cdot t}\right)$$

The average concentration in the shower room during showering is given by:

$$C_{asav1} = \left(\frac{ksw}{ksa}\right) C_{ws} \left[1 - \left(\frac{1}{ksa \cdot T_1}\right) \left(1 - e^{-ksa \cdot T_1}\right)\right]$$

The transfer factor TF_{sh1} is given by:

$$TF_{sh1} = \left(\frac{ksw}{ksa}\right) \left[1 - \left(\frac{1}{ksa \cdot T_1}\right) \left(1 - e^{-ksa \cdot T_1}\right)\right]$$

In order to solve this equation, the parameter *fv* must be determined. Foster and Chrostowski (1987) estimated *fv* by assuming the shower water atomizes into droplets and considering the rate of volatilization from a droplet and the time of descent for the droplet. Their expression for *fv* is:

$$fv = 1 - \exp\left(\frac{-kao \cdot tdr}{60 \cdot d}\right)$$

where:

kao = overall mass transfer coefficient (cm/hr);
tdr = shower droplet drop time (sec); and
d = droplet diameter (mm).

The term *kao/(60d)* combines both the rate of transfer and the available interfacial area across which volatilization can occur. The value *1/(60d)* equals the specific interfacial area, *6/d*, for a spherical shower droplet of diameter *d* multiplied by conversion factors (hr/3600 sec and 10 mm/cm). The overall mass transfer coefficient, *kao*, is based on an ambient overall mass transfer coefficient, *ko*, that is adjusted for the higher shower water temperature.

$$kao = ko \cdot \left(\frac{Tms \cdot ma}{Tma \cdot ms}\right)^{0.5}$$

In this expression:

ko = ambient overall mass transfer coefficient (cm/hr);
Tms = shower water temperature (˚K);
ms = water viscosity at shower temperature (cp);
Tma = ambient temperature (˚K); and
ma = water viscosity at ambient temperature (cp).

The ambient overall mass transfer coefficient is given by:

$$ko = \left(\frac{1}{kw} + \frac{R \cdot Tma}{H \cdot kg}\right)^{-1}$$

where:

kw = mass transfer resistance through the water (cm/hr);
R = gas constant, 8.2 x 10^{-5} atm-m^3/mol-K;
H = Henry's law constant (atm-m^3/mol); and
kg = mass transfer resistance through the gas (cm/hr).

The following empirical relationships are used for the water and gas mass transfer coefficients.

$$kw = 20 \cdot \left(\frac{44}{MW} \right)^{0.5}$$

$$kg = 3000 \cdot \left(\frac{18}{MW} \right)^{0.5}$$

where:

MW = molecular weight of the chemical (g/mol).

The transfer factor TF_{sh2} is determined by generating an expression for C_{asav2} which depends on C_{ws}. The quantity C_{asav2} is the average concentration of chemical in the shower room air after showering and is found by solving:

$$C_{asav2} = \frac{\int_0^{T_2} C_{as}(t)\ dt}{T_2}$$

The concentration of the chemical in the shower room, $C_{as}\ (t)$, is found by solving the following differential equation:

$$Vsh \cdot \frac{d}{dt} C_{as} = - Qash \cdot C_{as}$$

This equation is similar to the previous differential equation for C_{as} except the source term, *rsh*, is now zero since the shower is off. The solution to this equation is:

$$C_{as}(t) = C_{as2z}\ e^{-ksa \cdot t}$$

The parameter *ksa* was defined previously, and the variable C_{as2z} is the concentration in the shower room when the shower is turned off and is given by:

$$C_{as2z} = \left(\frac{ksw}{ksa} \right) C_{ws} \left(1 - e^{-ksa \cdot T_1}\right)$$

The average concentration of the chemical in the air following showering is given by:

$$C_{asav2} = \frac{C_{as2z}}{ksa \cdot T_2} (1 - e^{-ksa \cdot T_2})$$

Substituting the expression for C_{as2z} into the equation yields:

$$C_{asav2} = \left(\frac{ksw}{ksa^2 \cdot T_2} \right) (1 - e^{-ksa \cdot T_1}) (1 - e^{-ksa \cdot T_2}) C_{ws}$$

The transfer factor TF_{sh2} is therefore given by:

$$TF_{sh2} = \left(\frac{ksw}{ksa^2 \cdot T_2} \right) (1 - e^{-ksa \cdot T_1}) (1 - e^{-ksa \cdot T_2})$$

2.2 Results

The results of running the model are presented in Table 2-1. The values for the volume of the shower room, *Vsh*, the rate of air flow through the shower room, *Qash*, the rate of water flow from the shower, *Qwsh*, fall time for a water droplet, *tdr*, diameter of water droplet, *d*, ambient temperature, *Tma*, shower water temperature, *Tms*, and viscosities of water at different temperatures come from Foster and Chrostowski (1987). The time spent in the shower, T_1, is also from Foster and Chrostowski (1987), while T_2 was selected to sum with T_1 to be 0.25 hr or 15 minutes, the typical time spent showering. The molecular weight, *MW*, and Henry's law constant, *H*, were taken from EPA (1996), Mackay et al. (1992a) or Mackay et al. (1992b).

3 Bath Water to Air Volatilization Model

3.1 Equations

During a bath, chemicals present in the bath water are assumed to have the opportunity to volatilize into the air within the bathroom. Initially, the concentration of a chemical in the bathroom in the air is assumed to be zero. As time goes on, the concentration increases until the bath is finished. At this time, the concentration in the air begins to decrease as air turns over in the room. Figure 3-1 depicts the evolution of the bathroom air concentrations over time. The individual taking a bath is assumed to be in the bathroom during the bath and for a period after the bath. The relevant exposure point concentration for this individual is the average concentration of the chemical in the air during this exposure event, since the individual is assumed to maintain a constant inhalation rate both during and after the bath.

To estimate this average concentration in the bathroom air, the shower water to air volatilization model of Foster and Chrostowski (1987) was modified. The model is based on a simple box model of air exchange in the bathroom with constant emission of chemicals during the bath. The average concentration in the bathroom air is the time weighted sum of the average concentration in the bathroom air during the bath and the average concentration in the bathroom air after the bath is completed.

$$C_{abav} = \frac{C_{abav1} \cdot T_1 + C_{abav2} \cdot T_2}{T_1 + T_2}$$

where:

C_{abav} = average concentration of chemical in the bathroom air (mg/m^3);
C_{abav1} = average concentration of chemical in the bathroom air during the bath (mg/m^3);
C_{abav2} = average concentration of chemical in the bathroom air after the bath (mg/m^3);
T_1 = duration of the bath (hours); and
T_2 = period individual is in bathroom after the bath (hours).

Both C_{abav1} and C_{abav2} depend upon the concentration of the chemical in the bath water and this relationship can be expressed through a transfer factor such that the following relationships and transfer factors can be defined:

$$C_{abav1} = TF_{bwa1} \cdot C_{wb}$$

$$C_{abav2} = TF_{bwa2} \cdot C_{wb}$$

$$C_{abav} = TF_{bwa} \cdot C_{wb}$$

$$TF_{bwa} = \frac{TF_{bwa1} \cdot T_1 + TF_{bwa2} \cdot T_2}{T_1 + T_2}$$

where:

C_{wb} = concentration of chemical in the bath water (mg/L);
TF_{bwa1} = transfer factor describing relationship between concentration in bathroom air and bath water during the bath (L/m^3);
TF_{bwa2} = transfer factor describing relationship between concentration in bathroom air and bath water after the bath (L/m^3); and
TF_{bwa} = overall transfer factor describing overall relationship between concentration in bathroom air and bath water (L/m^3).

The variable TF_{bwa1} is determined by first developing an expression for C_{abav1}. This variable is determined by solving the following equation:

$$C_{abav1} = \frac{\int_0^{T_1} C_{ab}(t)\ dt}{T_1}$$

where:

$C_{ab}(t)$ = concentration of chemical in the bathroom air over time (mg/m^3).

The variable $C_{ab}(t)$ can be determined by solving the following differential equation:

$$Vbrm \cdot \frac{d}{dt} C_{ab}(t) = rbrm - Qabrm \cdot C_{ab}(t)$$

where:

Vbrm	=	volume of bathroom (m^3);
rbrm	=	rate of chemical emission into bathroom (mg/hr); and
Qabrm	=	rate of air flow out of bathroom (m^3/hr).

This equation states that the rate at which the mass of chemical in the bathroom changes depends on the difference in the rate at which the chemical is volatilized from the bath water minus the rate at which the chemical leaves the bathroom as air circulates through the bathroom.

The rate at which the chemical is introduced into the bathroom from bath water is the mass of the chemical in the bath water times the fraction volatilized during the bath. Thus, the rate at which the chemical is introduced into the bathroom is given by:

$$rbrm = \frac{fv \cdot Vbw \cdot C_{wb}}{T_1}$$

where:

fv	=	fraction of chemical volatilized; and
Vbw	=	volume of bath water (m^3).

The differential equation describing the change in C_{as} over time becomes:

$$\frac{d}{dt} C_{ab} = \frac{fv \cdot Vbw}{T_1 \cdot Vbrm} \cdot C_{wb} - \frac{Qabrm}{Vbrm} \cdot C_{ab}$$

By defining two rate constants, *kbw* and *kba*, this equation can be restated:

$$\frac{d}{dt} C_{ab} = kbw \cdot C_{wb} - kba \cdot C_{ab}$$

The constants *kbw* and *kba* are defined as:

$$kbw = \frac{fv \cdot Vbw}{T_1 \cdot Vbrm}$$

where:

$$kba = \frac{Qabrm}{Vbrm}$$

kbw = first order rate constant describing release of chemical from bath water to air (L/m^3-hr); and

kba = first order rate constant describing turnover of air in bathroom (1/hr).

The solution to this differential equation is:

$$C_{ab}(t) = \left(\frac{kbw}{kba}\right) C_{wb} \left(1 - e^{-kba \cdot t}\right)$$

The average concentration in the bathroom during the bath is given by:

$$C_{abav1} = \left(\frac{kbw}{kba}\right) C_{wb} \left[1 - \left(\frac{1}{kba \cdot T_1}\right) \left(1 - e^{-kba \cdot T_1}\right)\right]$$

The transfer factor TF_{bwa1} is given by:

$$TF_{bwa1} = \left(\frac{kbw}{kba}\right) \left[1 - \left(\frac{1}{kba \cdot T_1}\right) \left(1 - e^{-kba \cdot T_1}\right)\right]$$

In order to solve this equation, the parameter *fv* must be determined. This parameter is estimated by determining the change in concentration of the chemical in the bath water which depends on the rate of volatilization. The rate at which the chemical is emitted from the bath water is given by:

$$Vbw \cdot \frac{d}{dt} Cwb = - kao \cdot Abw \cdot CF1 \cdot C_{wb}$$

where:

kao = overall mass transfer coefficient (cm/hr);
Abw = area of the bath water (m^2); and
CF1 = conversion factor (10^{-2} m/cm).

The solution to this differential equation is:

$$C_{wb}(t) = C_{wbz}\, e^{-\left(\frac{kao \cdot Abw \cdot CF1}{Vbw}\right)}$$

where:

Cwbz = initial concentration in bath water (mg/L).

The fraction volatilized at time T_1 is:

$$fv = 1 - \left(\frac{C_{wb}(t)}{C_{wbz}}\right)$$

or

$$fv = 1\, e^{-\left(\frac{kao \cdot Abw \cdot CF1}{Vbw}\right) T_1}$$

The overall mass transfer coefficient, *kao*, is based on an ambient overall mass transfer coefficient that is adjusted for the higher bath water temperature.

$$kao = ko \cdot \left(\frac{Tmb \cdot ma}{Tma \cdot mb}\right)^{0.5}$$

In this expression:

ko = ambient overall mass transfer coefficient (cm/hr);
Tmb = bath water temperature (˚K);
ms = water viscosity at bath water temperature (cp);

Tma = ambient temperature (˚K); and
ma = water viscosity at ambient temperature (cp).

The ambient overall mass transfer coefficient is given by:

$$ko = \left(\frac{1}{kw} + \frac{R \cdot Tma}{H \cdot kg} \right)^{-1}$$

where:

kw = mass transfer resistance through the water (cm/hr);
R = gas constant, 8.2 x 10^{-5} atm-m^3/mol-K;
H = Henry's law constant (atm-m^3/mol); and
kg = mass transfer resistance through the gas (cm/hr).

The following empirical relationships are used for the water and gas mass transfer coefficients.

$$kw = 20 \cdot \left(\frac{44}{MW} \right)^{0.5}$$

$$kg = 3000 \cdot \left(\frac{18}{MW} \right)^{0.5}$$

where:

MW = molecular weight of the chemical (g/mol).

The transfer factor TF_{bwa2} is determined by generating an expression for C_{abav2} which depends on C_{wb}. The quantity C_{abav2} is the average concentration of chemical in the bathroom air after the bath and is found by solving:

$$C_{abav2} = \frac{\int_0^{T_2} C_{ab}(t)\ dt}{T_2}$$

The concentration of the chemical in the bathroom, $C_{ab}(t)$, is found by solving the following differential equation:

$$Vbrm \cdot \frac{d}{dt} C_{ab} = - Qabrm \cdot C_{ab}$$

This equation is similar to the previous differential equation for C_{ab} except the source term, *rbrm*, is now zero since the bath water has been drained. The solution to this equation is:

$$C_{ab}(t) = C_{ab2z} \, e^{- kba \cdot t}$$

The parameter *kba* was defined previously, and the variable C_{ab2z} is the concentration in the bathroom when the bath water drains and is given by:

$$C_{ab2z} = \left(\frac{kbw}{kba} \right) C_{wb} \left(1 - e^{- kba \cdot T_1} \right)$$

The average concentration of the chemical in the air following the bath is given by:

$$C_{abav2} = \frac{C_{ab2z}}{kba \cdot T_2} \left(1 - e^{- kba \cdot T_2} \right)$$

Substituting the expression for C_{as2z} into the equation yields:

$$C_{abav2} = \left(\frac{kbw}{kba^2 \cdot T_2} \right) (1 - e^{- kba \cdot T_1}) (1 - e^{- kba \cdot T_2}) \, C_{wb}$$

The transfer factor TF_{bwa2} is given by:

$$TF_{bwa2} = \left(\frac{kbw}{kba^2 \cdot T_2} \right) (1 - e^{- kba \cdot T_1}) (1 - e^{- kba \cdot T_2})$$

3.2 Results

The results of running the model are presented in Table 3-1. The values for the volume of the bathroom, *Vbrm*, and rate of air flow through the bathroom, *Qabrm*,

were taken from Foster and Chrotowski (1987). The area of bath water, *Abw*, and the depth of the bath water, *dbw*, were estimated from a typical bath (approximately 4 feet by 2 feet for the area and 8 inches for the depth). The quantity ***Abw · dbw*** gives *Vbw*. The ambient temperature of water, *Tma*, and the viscosity at this temperature is taken from Foster and Chrostowski (1987). The temperature of the bath water was estimated while the viscosity of water at this temperature was estimated from Linsley and Franzini (1979). The time spent in a bath, T_1, was estimated to be 0.25 hr or 15 minutes, while T_2 was selected to sum with T_1 to be 0.33 hr or 20 minutes, the typical time in the bathroom during and just after a bath. The molecular weight, *MW* and Henry's law constant, *H*, were taken from EPA (1996), Mackay et al. (1992a) or Mackay et al. (1992b).

4 Surface Water to Air Volatilization Model

4.1 Equations

Ambient concentrations of chemicals in air resulting from volatilization from surface water may be estimated as follows:

$$C_{oa} = TF_{swoa} \cdot C_{sw}$$

where:

C_{oa} = concentration of chemical in outdoor air (mg/m^3);
TF_{swoa} = transfer factor from surface water to outdoor air (L/m^3); and
C_{sw} = concentration of chemical in surface water (mg/L).

The transfer factor, TF_{swoa}, describes the relationship between the concentration in outdoor air and the concentration in surface water and is given by the following expression:

$$TF_{swoa} = DF_{swoa} \cdot FF_{swoa} \cdot CF1$$

where:

DF_{swoa} = dispersion factor [(m^2-s)/(m^3)];
FF_{swoa} = flux factor (m/s); and
$CF1$ = conversion factor (1000 L/m^3).

The dispersion factor, DF_{swoa}, translates a flux of a chemical from surface water to an air concentration. The flux factor, FF_{swoa}, is given by the following expression:

$$FF_{swoa} = K_{ol} \cdot CF2$$

where:

K_{ol} = overall mass-transfer coefficient (m/day); and
$CF2$ = conversion factor (day/86,400 sec).

The overall mass-transfer coefficient is dependent on the physical and chemical properties of the compound as well as environmental conditions (Achman et al., 1993). The reciprocal of K_{ol} is the total resistance to transfer expressed on a water and vapor phase basis and is given by the following expression (Achman et al., 1993])

$$\frac{1}{K_{ol}} = \frac{1}{k_w} + \frac{RT}{Hk_a}$$

where:

k_w = water phase mass-transfer coefficient (m/day);
k_a = vapor phase mass-transfer coefficient (m/day);
R = universal gas constant (atm-m^3/mol-K);
T = absolute temperature (K); and
H = Henry's law constant (atm-m^3/mol).

The water phase mass-transfer coefficient for a particular chemical, k_w, can be related to the water phase mass-transfer coefficient for carbon dioxide (CO_2) through an empirical relationship involving a dimensionless number known as the Schmidt number (Sc) (Achman et al., 1993):

$$k_w = k_{w(CO_2)} \cdot \left(\frac{Sc}{Sc_{(CO_2)}} \right)^{nw} \cdot CF3$$

where:

$k_{w(CO_2)}$ = water phase mass-transfer coefficient for CO_2 (cm/hr);
Sc = Schmidt number for the chemical;
$Sc_{(CO_2)}$ = Schmidt number for CO_2;
nw = an empirical coefficient; and
CF3 = conversion factor (0.24 m/day per cm/hr).

An expression for $k_{w(CO_2)}$ that is dependent on windspeed (Achman et al., 1993) is:

$$k_{w_{(CO_2)}} = 0.17 \cdot u_{10} \qquad \text{for } u_{10} < 3.6 \text{ m/s}$$

$$k_{w_{(CO_2)}} = 2.85 \cdot u_{10} - 9.65 \qquad \text{for } 3.6 < u_{10} < 13 \text{ m/s}$$

$$k_{w_{(CO_2)}} = 5.9 \cdot u_{10} - 49.3 \qquad \text{for } u_{10} > 13 \text{ m/s}$$

where u_{10} is the wind speed at a reference height of 10m (in units of m/s) and $k_{w(CO_2)}$ has units of cm/hr. The Schmidt number of a chemical is given by the following expression (Achman et al., 1993):

$$Sc = \frac{\nu_w}{D_w}$$

where:

ν_w = kinematic viscosity of water (cm^2/s); and
D_w = diffusivity of a chemical through water (cm^2/s).

Achman et al. (1993) give a Schmidt number for carbon dioxide through water of 600 and indicated that *nw* is equal to -2/3 for u_{10} less than 3.6 m/s or -1/2 for u_{10} greater than 3.6 m/s.

The vapor phase mass-transfer coefficient, k_a, can be related to the vapor phase mass-transfer coefficient for water vapor, $k_{a(H_2O)}$, through an empirical equation involving diffusivities in air (Achman et al.):

$$k_a = k_{a(H_2O)} \cdot \left(\frac{D_a}{D_{a(H_2O)}} \right)^{na} \cdot CF4$$

where:

$k_{a(H_2O)}$ = vapor phase mass-transfer coefficient for water vapor (cm/sec);
D_a = diffusivity of the chemical in air (cm^2/sec);
$D_{a(H_2O)}$ = diffusivity of water vapor in air (cm^2/sec);
na = an empirical coefficient; and
CF4 = conversion factor (864 m/day per cm/sec).

The vapor phase mass-transfer coefficient for water vapor, $k_{a(H_2O)}$, is given by the following empirical equation (Achman et al., 1993):

$$k_{a(H_2O)} = 0.2\ u_{10} + 0.3$$

where $k_{a(H2O)}$ has units of cm/sec. Achman et al. (1993) estimate *na* to be 0.61.

For this analysis, the dispersion factor, DF_{swoa}, was determined from Q/C data in the EPA Soil Screening Guidance (EPA, 1996). The parameter Q/C is the inverse of the concentration in the center of a square surface source. Values of Q/C are given for Chicago for six areas:

Area (acre)	Q/C (g/m^2-s) per (kg/m^3)
0.5	97.78
1	85.81
2	76.08
5	65.75
10	59.16
30	50.60

The values of Q/C were translated into values of DF_{swoa} through the following equation:

$$DF_{swoa} = \frac{10^3 g/kg}{(Q/C)}$$

This expression gives DF_{swoa} in the correct units of m^2-s/m^3. The resulting values for DF_{swoa} as a function of area were then fit to the following equation through regression analysis:

$$DF_{swoa} = C_1 \cdot A^{C_2}$$

where:

A = area of surface source (acres).

The regression analysis yielded the following values for C_1 and C_2:

$$C_1 = 11.62$$
$$C_2 = 0.1604$$

Figure 4-1 presents the values of DF_{swoa} as a function of area and the fitted line through the data.

4.2 Results

The model requires a number of system parameters and chemical properties entered as inputs. The system parameters include the temperature (T), the source area (A), the wind speed (u_{10}), the kinematic viscosity of water (ν_w), and the vapor phase diffusivity of water ($D_{a(H_2O)}$). The temperature T was estimated to be about 288°K (15°C or 59°F) and the vapor phase diffusivity of water $D_{a(H_2O)}$ was estimated to be 0.24 cm^2/s (Weast et al., 1984). The average wind speed for Green Bay was used in this analysis (GRI, 1987). The areas A for the different areas of interest (AOI) were estimated as indicated in Attachment 1. These areas were used in the regression equation to calculate a value of DF_{swoa} for each AOI. The values for the chemical properties water phase diffusivity, D_w, vapor phase diffusivity, D_a, and Henry's Law constant, H, were taken from EPA (1996), Mackay et al. (1992a) or Mackay et al. (199b). The results for the Little Lake Butte des Morts, Appleton to Little Rapids, Little Rapids to DePere and DePere to Green Bay reaches are provided in Tables 4-1 through 4-4, respectively. Table 4-5 presents results for Green Bay.

5 Sediment to Pore Water Partitioning Model

5.1 Equations

The concentration of chemicals in sediment pore water can be estimated from the following equation:

$$C_{pw} = TF_{sdpw} \cdot C_{sed}$$

where:

C_{pw} = concentration of chemical in sediment pore water (mg/L);
TF_{sdpw} = transfer factor from sediment to sediment pore water ((mg/L)/(mg/Kg)); and
C_{sed} = concentration of chemical in sediment (mg/kg).

The transfer factor, TF_{sdpw}, is the inverse of the sediment to pore water partitioning coefficient, Kp:

$$TF_{sdpw} = \frac{1}{K_p}$$

The sediment to pore water partitioning coefficient depends on the type of chemical. For organic chemicals, the partitioning coefficient is given by:

$$Kp = foc \cdot Koc$$

where:

Kp = sediment to pore water partitioning coefficient ((mg/kg)/(mg/L));
foc = fraction organic carbon in sediment (kg-oc/kg-sed); and
Koc = organic carbon to water partitioning coefficient.

For inorganic chemicals, a partitioning coefficient that is dependent on pH is given in EPA (1996).

5.2 Results

The sediment to pore water partitioning coefficients for chemicals of potential concern are provided for the Appleton to Little Rapids, Little Rapids to DePere and DePere to Green Bay reaches in Tables 5-1 through 5-4, respectively. Table 5-5 provides sediment to pore water partitioning coefficients for Green Bay. For each location, the fraction of organic carbon, *foc*, was taken as the arithmetic average of the fraction organic carbon in all sediment samples. The organic carbon to water partitioning coefficients for organic chemicals were obtained from EPA (1996), Mackay et al. (1992a) or Mackay et al. (1992b). These values are provided in the column labeled *Koc* with a *Koc* Type of 1. The sediment to water partitioning coefficient for inorganic chemicals is provided in the column labeled *Koc* with *Koc* Type equal to 3. These values were obtained from EPA (1996) for a pH of 6.8.

6 References

Achman, D.R., Hornbuckle, K.C. and Elsenreich, S.J., 1993, Volatilization of Polychlorinated Biphenyls from Green Bay, Lake Michigan. Environmental Science and Technology, Vol. 27 (1), pp. 75-87.

Foster, S.A. and P.C. Chrostowski, 1987, "Inhalation Exposures to Volatile Organic Contaminants in the Shower." Presented at the 80th Annual Meeting of Air Pollution Control Association, New York, NY, June 21-26, 1987.

Gas Research Institute (GRI), 1987, Management of Manufactured Gas Plant Sites, Volume III:Risk Assessment, Chicago, IL.

Linsley, R. and Franzini, J., 1979, Water-Resources Engineering. McGraw-Hill Book Company, New York, NY.

Mackay, D., W.Y. Shiu, and K.C. Ma, 1992a, Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals. Volume I: Monoaromatic Hydrocarbons, Chlorobenzenes, and PCBs. Lewis Publishers, Chelsea, Michigan.

Mackay, D., W.Y. Shiu, and K.C. Ma, 1992b, Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals. Volume II: Polynuclear Aromatic Hydrocarbons, Polychlorinated Dioxins, and Dibenzofurans. Lewis Publishers, Chelsea, Michigan.

USEPA, 1996. Soil Screening Guidance: User's Guide, Office of Solid Waste and Emergency Response, 9355. 4-23, EPA/540/R-96/018, April.

Weast, R., Astle, M. and Beyer, W. (eds.), 1984, CRC Handbook of Chemistry and Physics, CRC Press, Boca Raton, FL.

Appendix B4

Exposure Point Concentrations, Unit Cancer Risks, Unit Hazard Indices, Cancer Risks, and Hazard Indices for Different Receptors

This appendix provides exposure point concentrations for each reach of the Lower Fox River and Green Bay, and unit cancer risks, unit hazard indices, cancer risks and hazard indices for the following receptors:

- recreational anglers;
- high intake fish consumers;
- hunters;
- drinking water users;
- local residents;
- recreational water users; and
- marine construction workers.

Exposure Point Concentrations for Reaches:

- Little Lake Butte des Morts Reach - Upperbound
- Little Lake Butte des Morts Reach - Average
- Appleton to Little Rapids Reach - Upperbound
- Appleton to Little Rapids Reach - Average
- Little Rapids to DePere Reach - Upperbound
- Little Rapids to DePere Reach - Average
- DePere to Green Bay Reach - Upperbound
- DePere to Green Bay Reach - Average
- Green Bay - Upperbound
- Green Bay - Average

Receptor: Recreational Angler

Exposure Scenario: RME Assumptions (with Upperbound Concentrations)

Areas Evaluated: Little Lake Butte des Morts Reach
Appleton to Little Rapids Reach
Little Rapids to DePere Reach
DePere to Green Bay Reach
Green Bay

Exposure Pathways: Ingestion of Fish
Incidental Ingestion of Surface Water
Dermal Contact with Surface Water
Inhalation of Volatiles in Outdoor Air

Receptor: Recreational Angler

Exposure Scenario: RME Assumptions (with Average Concentrations)

Areas Evaluated: Little Lake Butte des Morts Reach
Appleton to Little Rapids Reach
Little Rapids to DePere Reach
DePere to Green Bay Reach
Green Bay

Exposure Pathways: Ingestion of Fish
Incidental Ingestion of Surface Water
Dermal Contact with Surface Water
Inhalation of Volatiles in Outdoor Air

Receptor: Recreational Angler

Exposure Scenario: CTE Assumptions (with Average Concentrations)

Areas Evaluated: Little Lake Butte des Morts Reach
Appleton to Little Rapids Reach
Little Rapids to DePere Reach
DePere to Green Bay Reach
Green Bay

Exposure Pathways: Ingestion of Fish
Incidental Ingestion of Surface Water
Dermal Contact with Surface Water
Inhalation of Volatiles in Outdoor Air

Receptor: High Intake Fish Consumer

Exposure Scenario: RME Assumptions (with Upperbound Concentrations)

Areas Evaluated: Little Lake Butte des Morts Reach
Appleton to Little Rapids Reach
Little Rapids to DePere Reach
DePere to Green Bay Reach
Green Bay

Exposure Pathways: Ingestion of Fish
Incidental Ingestion of Surface Water
Dermal Contact with Surface Water
Inhalation of Volatiles in Outdoor Air

Receptor: High Intake Fish Consumer

Exposure Scenario: RME Assumptions (with Average Concentrations)

Areas Evaluated: Little Lake Butte des Morts Reach
Appleton to Little Rapids Reach
Little Rapids to DePere Reach
DePere to Green Bay Reach
Green Bay

Exposure Pathways: Ingestion of Fish
Incidental Ingestion of Surface Water
Dermal Contact with Surface Water
Inhalation of Volatiles in Outdoor Air

Receptor: High Intake Fish Consumer

Exposure Scenario: CTE Assumptions (with Average Concentrations)

Areas Evaluated: Little Lake Butte des Morts Reach
Appleton to Little Rapids Reach
Little Rapids to DePere Reach
DePere to Green Bay Reach
Green Bay

Exposure Pathways: Ingestion of Fish
Incidental Ingestion of Surface Water
Dermal Contact with Surface Water
Inhalation of Volatiles in Outdoor Air

Receptor: Hunter

Exposure Scenario: RME Assumptions (with Upperbound Concentrations)

Areas Evaluated: Little Lake Butte des Morts Reach
Appleton to Little Rapids Reach
Little Rapids to DePere Reach
DePere to Green Bay Reach
Green Bay

Exposure Pathways: Ingestion of Waterfowl
Incidental Ingestion of Surface Water
Dermal Contact with Surface Water
Inhalation of Volatiles in Outdoor Air

Receptor: Hunter

Exposure Scenario: RME Assumptions (with Average Concentrations)

Areas Evaluated: Little Lake Butte des Morts Reach
Appleton to Little Rapids Reach
Little Rapids to DePere Reach
DePere to Green Bay Reach
Green Bay

Exposure Pathways: Ingestion of Waterfowl
Incidental Ingestion of Surface Water
Dermal Contact with Surface Water
Inhalation of Volatiles in Outdoor Air

Receptor: Hunter

Exposure Scenario: CTE Assumptions (with Average Concentrations)

Areas Evaluated: Little Lake Butte des Morts Reach
Appleton to Little Rapids Reach
Little Rapids to DePere Reach
DePere to Green Bay Reach
Green Bay

Exposure Pathways: Ingestion of Waterfowl
Incidental Ingestion of Surface Water
Dermal Contact with Surface Water
Inhalation of Volatiles in Outdoor Air

Receptor: Drinking Water User

Exposure Scenario: RME Assumptions (with Upperbound Concentrations)

Areas Evaluated: Little Lake Butte des Morts Reach
Appleton to Little Rapids Reach
Little Rapids to DePere Reach
DePere to Green Bay Reach
Green Bay

Exposure Pathways: Ingestion of Surface Water
Dermal Contact with Surface Water
Inhalation of Volatiles in Indoor Air

Receptor: Drinking Water User

Exposure Scenario: RME Assumptions (with Upperbound Concentrations and Recent Mercury Data)

Areas Evaluated: Little Lake Butte des Morts Reach
Appleton to Little Rapids Reach
Little Rapids to DePere Reach
DePere to Green Bay Reach
Green Bay

Exposure Pathways: Ingestion of Surface Water
Dermal Contact with Surface Water
Inhalation of Volatiles in Indoor Air

Receptor: Local Resident

Exposure Scenario: RME Assumptions (with Upperbound Concentrations)

Areas Evaluated: Little Lake Butte des Morts Reach
Appleton to Little Rapids Reach
Little Rapids to DePere Reach
DePere to Green Bay Reach
Green Bay

Exposure Pathways: Inhalation of Volatiles in Outdoor Air

Receptor: Local Resident

Exposure Scenario: RME Assumptions (with Upperbound Concentrations and Recent Mercury Data)

Areas Evaluated: Little Lake Butte des Morts Reach
Appleton to Little Rapids Reach
Little Rapids to DePere Reach
DePere to Green Bay Reach
Green Bay

Exposure Pathways: Inhalation of Volatiles in Outdoor Air

Receptor: Recreational Water User: Swimmer

Exposure Scenario: RME Assumptions (with Upperbound Concentrations)

Areas Evaluated: Little Lake Butte des Morts Reach
Appleton to Little Rapids Reach
Little Rapids to DePere Reach
DePere to Green Bay Reach
Green Bay

Exposure Pathways: Incidental Ingestion of Surface Water
Dermal Contact with Surface Water
Inhalation of Volatiles in Outdoor Air
Incidental Ingestion of Sediments
Dermal Contact with Sediment Pore Water

Receptor: Recreational Water User: Wader

Exposure Scenario: RME Assumptions (with Upperbound Concentrations)

Areas Evaluated: Little Lake Butte des Morts Reach
Appleton to Little Rapids Reach
Little Rapids to DePere Reach
DePere to Green Bay Reach
Green Bay

Exposure Pathways: Incidental Ingestion of Surface Water
Dermal Contact with Surface Water
Inhalation of Volatiles in Outdoor Air
Incidental Ingestion of Sediments
Dermal Contact with Sediment Pore Water

Receptor: Marine Construction Worker

Exposure Scenario: RME Assumptions (with Upperbound Concentrations)

Areas Evaluated: Little Lake Butte des Morts Reach
Appleton to Little Rapids Reach
Little Rapids to DePere Reach
DePere to Green Bay Reach
Green Bay

Exposure Pathways: Incidental Ingestion of Surface Water
Dermal Contact with Surface Water
Inhalation of Volatiles in Outdoor Air
Incidental Ingestion of Sediments
Dermal Contact with Sediments

Appendix B5

Concentrations of Lead in Surface Sediment, Surface Water, Fish Tissue, and Waterfowl Tissue Samples

Table 1 Lead Concentrations in Surface Sediment Samples

LOCATION	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE DATE	RESULT (mg/kg)
Little Lake Butte des Morts	D-RI-Comp1(0-2)	Surface Sediment		3.99 J
Little Lake Butte des Morts	D-RI-Comp2(0-2)	Surface Sediment		160 J
Little Lake Butte des Morts	E-RI-Comp1(0-2)	Surface Sediment		7.10
Little Lake Butte des Morts	E-RI-Comp2(0-2)	Surface Sediment		7.79
Little Lake Butte des Morts	P-RI-Comp1(0-2)	Surface Sediment		6.08
Little Lake Butte des Morts	2C2 (Tr)	Surface Sediment	1993	300
Little Lake Butte des Morts	POG (Tr)	Surface Sediment	1992	110
Little Lake Butte des Morts	2E8 (Tr)	Surface Sediment	1993	99
Little Lake Butte des Morts	SDC-C-1-P-S	Surface Sediment	06/05/1998	262
Little Lake Butte des Morts	SDC-C-3-P-S	Surface Sediment	06/05/1998	162
Little Lake Butte des Morts	SDC-E-1-P-S	Surface Sediment	06/05/1998	289
Little Lake Butte des Morts	SDC-E-3-P-S	Surface Sediment	06/05/1998	39
Appleton to Little Rapids	N-RI-Comp1(0-2)	Surface Sediment		5.43
Appleton to Little Rapids	N-RI-Comp2(0-2)	Surface Sediment		5.17
Appleton to Little Rapids	N-RI-Comp3(0-2)	Surface Sediment		7.25
Appleton to Little Rapids	N (Tr)	Surface Sediment	1992	280
Little Rapids to Depere	EGH-RI-Comp1(0-2)	Surface Sediment		6.15
Little Rapids to Depere	X (Tr)	Surface Sediment	1992	130
Little Rapids to Depere	HH (Tr)	Surface Sediment	1992	1400
Little Rapids to Depere	SDC-EE26-5-P-S	Surface Sediment	06/01/1998	297
Little Rapids to Depere	SDC-EE26-1-P-S	Surface Sediment	06/01/1998	123
Little Rapids to Depere	SDC-EE25-1-P-S	Surface Sediment	06/02/1998	148
Little Rapids to Depere	SDC-EE25-3-P-S	Surface Sediment	06/02/1998	72
Little Rapids to Depere	SDC-EE24-1-P-S	Surface Sediment	06/02/1998	62
Little Rapids to Depere	SDC-EE24-3-P-S	Surface Sediment	06/02/1998	70
Little Rapids to Depere	SDC-EE22-3-P-S	Surface Sediment	06/03/1998	126
Little Rapids to Depere	SDC-EE22-2-P-S	Surface Sediment	06/03/1998	68
Little Rapids to Depere	SDC-EE23-2-P-S	Surface Sediment	06/03/1998	74
Little Rapids to Depere	SDC-EE23-3-P-S	Surface Sediment	06/03/1998	68
Little Rapids to Depere	SDC-W-2-P-S	Surface Sediment	06/04/1998	60
Little Rapids to Depere	SDC-W-3-P-S	Surface Sediment	06/04/1998	57
Little Rapids to Depere	SDC-X-1-P-S	Surface Sediment	06/04/1998	84
Little Rapids to Depere	SDC-X-3-P-S	Surface Sediment	06/04/1998	71
DePere to Green Bay	95002-01	Surface Sediment		104.432
DePere to Green Bay	95004-01	Surface Sediment		90.64
DePere to Green Bay	95006-01	Surface Sediment		39.64
DePere to Green Bay	95007-01	Surface Sediment		75.44
DePere to Green Bay	95008-01	Surface Sediment		96.24
DePere to Green Bay	95010-01	Surface Sediment		104.406
DePere to Green Bay	95011-01	Surface Sediment		84.24
DePere to Green Bay	95013-01	Surface Sediment		76.84
DePere to Green Bay	95016-01	Surface Sediment		38.24
DePere to Green Bay	95018-01	Surface Sediment		85.04
DePere to Green Bay	95020-01	Surface Sediment		140.425
DePere to Green Bay	95022-01	Surface Sediment		4.44
DePere to Green Bay	95025-01	Surface Sediment		80.64
DePere to Green Bay	95028-01	Surface Sediment		80.54
DePere to Green Bay	95030-01	Surface Sediment		77.94
DePere to Green Bay	95035-01	Surface Sediment		166.429
DePere to Green Bay	95038-01	Surface Sediment		110.431
DePere to Green Bay	95041-01	Surface Sediment		73.8
DePere to Green Bay	95044-01	Surface Sediment		69.74
DePere to Green Bay	95047-01	Surface Sediment		85.64
DePere to Green Bay	95049-01	Surface Sediment		77.9
DePere to Green Bay	95051-01	Surface Sediment		84.1
DePere to Green Bay	95052-01	Surface Sediment		65.4

Table 1 Lead Concentrations in Surface Sediment Samples

LOCATION	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE DATE	RESULT (mg/kg)
DePere to Green Bay	95054-01	Surface Sediment		76.74
DePere to Green Bay	95056-01	Surface Sediment		88.4
DePere to Green Bay	95058-01	Surface Sediment		73.3
DePere to Green Bay	95060-01	Surface Sediment		29.6
DePere to Green Bay	95061-01	Surface Sediment		83.2
DePere to Green Bay	95062-01	Surface Sediment		47.8
DePere to Green Bay	95064-01	Surface Sediment		9.3
DePere to Green Bay	95066-01	Surface Sediment		108
DePere to Green Bay	95068-01	Surface Sediment		76.2
DePere to Green Bay	95070-01	Surface Sediment		77.2
DePere to Green Bay	95071-01	Surface Sediment		80.8
DePere to Green Bay	95072-01	Surface Sediment		78.2
DePere to Green Bay	95074-01	Surface Sediment		88.5
DePere to Green Bay	95076-01	Surface Sediment		91.1
DePere to Green Bay	95077-01	Surface Sediment		85.4
DePere to Green Bay	95078-01	Surface Sediment		93.8
DePere to Green Bay	95079-01	Surface Sediment		74.9
DePere to Green Bay	95080-01	Surface Sediment		84.7
DePere to Green Bay	95081-01	Surface Sediment		98.5
DePere to Green Bay	95082-01	Surface Sediment		71.4
DePere to Green Bay	95084-01	Surface Sediment		83.8
DePere to Green Bay	95085-01	Surface Sediment		121
DePere to Green Bay	95086-01	Surface Sediment		85.6
DePere to Green Bay	95087-01	Surface Sediment		80.4
DePere to Green Bay	95088-01	Surface Sediment		89.8
DePere to Green Bay	95089-01	Surface Sediment		73.1
DePere to Green Bay	95090-01	Surface Sediment		128
DePere to Green Bay	95091-01	Surface Sediment		218
DePere to Green Bay	95092-01	Surface Sediment		96.5
DePere to Green Bay	95093-01	Surface Sediment		71.9
DePere to Green Bay	95094-01	Surface Sediment		52.1
DePere to Green Bay	95095-01	Surface Sediment		41.6
DePere to Green Bay	95096-01	Surface Sediment		17.2
DePere to Green Bay	95097-01	Surface Sediment		59.6
DePere to Green Bay	95098-01	Surface Sediment		41.9
DePere to Green Bay	95099-01	Surface Sediment		5.3
DePere to Green Bay	95100-01	Surface Sediment		40
DePere to Green Bay	95101-01	Surface Sediment		20.2
DePere to Green Bay	95102-01	Surface Sediment		79.6
DePere to Green Bay	95103-01	Surface Sediment		49
DePere to Green Bay	95104-01	Surface Sediment		19.1
DePere to Green Bay	95105-01	Surface Sediment		62.1
DePere to Green Bay	95106-01	Surface Sediment		62.1
DePere to Green Bay	95109-01	Surface Sediment		83.5
DePere to Green Bay	2FRB1 (Tr)	Surface Sediment	1993	99
DePere to Green Bay	2FRB22 (Tr)	Surface Sediment	1993	180
DePere to Green Bay	2FRB17 (Tr)	Surface Sediment	1993	27
DePere to Green Bay	FRB (Tr)	Surface Sediment	1992	350
DePere to Green Bay	SDC-DPD-1-P-S	Surface Sediment	06/03/1998	113
DePere to Green Bay	SDC-DPD-2-P-S	Surface Sediment	06/03/1998	89
DePere to Green Bay	SDC-DPD-3-P-S	Surface Sediment	06/03/1998	72
DePere to Green Bay	SDC-DPD-4-P-S	Surface Sediment	06/03/1998	20
DePere to Green Bay	SDC-DPD-5-P-S	Surface Sediment	06/03/1998	58
Reference	REF (Tr)	Surface Sediment	1993	20
Lake Winnebago	SDC-LW-1-P-S	Surface Sediment	06/08/1998	30

Table 1 Lead Concentrations in Surface Sediment Samples

LOCATION	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE DATE	RESULT (mg/kg)
Lake Winnebago	SDC-LW-2-P-S	Surface Sediment	06/08/1998	36
Lake Winnebago	SDC-LW-3-P-S	Surface Sediment	06/08/1998	39

Table 2 Lead Concentrations in Surface Water Samples

LOCATION	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE DATE	RESULT (ug/L)
Fox River at Princeton	Princeton	filtered water	Fall 91	0.066
Fox River at N. Lttl.Lk. Butte	NLLBDM	filtered water	Fall 91	0.117
Fox River at Wrightstown	Wrightstown	filtered water	Fall 92	0.118
Duck Creek at Oneida	Oneida	filtered water	Fall 92	0.0442
Fox River at Wrightstown	Wrightstown	filtered water	Spr. 93	0.124
Duck Creek at Oneida	Oneida	filtered water	Spr. 93	0.044
Fox River at Princeton	Princeton	unfiltered water	Fall 91	0.949
Fox River at N. Lttl.Lk. Butte	NLLBDM	unfiltered water	Fall 91	1.45
Fox River at Wrightstown	Wrightstown	unfiltered water	Fall 92	0.707
Duck Creek at Oneida	Oneida	unfiltered water	Fall 92	0.0733
Fox River at Wrightstown	Wrightstown	unfiltered water	Spr. 93	0.526
Duck Creek at Oneida	Oneida	unfiltered water	Spr. 93	0.264
Appleton Papers Intake	API_Intake	unfiltered water	3/1997	0.9
Green Bay Packaging Intake	GBPI_Intake	unfiltered water	8/1997	2.4
Green Bay Packaging Intake	GBPI_Intake	unfiltered water	8/1997	5.3
Nicolet Paper Intake	NP_Intake	unfiltered water	8/1997	1.1
Nicolet Paper Intake	NP_Intake	unfiltered water	8/1997	1.9
Thilmany Intake	T_Intake	unfiltered water	4/1997	1.49
Kerwin Paper Intake	KP_Intake	unfiltered water	3/1997	1.8
GBMSD River & Bay	GBMSD_Intake	unfiltered water	1993	1.45

Table 3 Lead Concentrations in Game Fish Tissue Samples

LOCATION	SAMPLE NUMBER	SPECIES	SAMPLE TYPE	SAMPDATE	RESULT (mg/kg)
Little Lake Butte des Morts	8602(d)	Carp	fillet and skin	09/04/1986	5 U
Little Lake Butte des Morts	8604(d)	Walleye	fillet and skin	09/04/1986	5 U
Little Lake Butte des Morts	8301(g)	Carp	whole fish	09/06/1983	5 U
Little Lake Butte des Morts	8601(e)	Walleye	whole fish	09/04/1986	5 U
Little Lake Butte des Morts	8603(c)	Carp	whole fish	09/04/1986	5 U
Little Lake Butte des Morts	7701(f)	Carp	whole fish	05/20/1977	5 U
Little Lake Butte des Morts	7702(f)	Carp	whole fish	05/20/1977	5 U
Little Lake Butte des Morts	7703(f)	Walleye	whole fish	05/20/1977	5 U
Little Lake Butte des Morts	7901(g)	Northern Pike	whole fish	08/20/1979	5 U
Little Lake Butte des Morts	7902(l)	White Sucker	whole fish	08/20/1979	5 U
Little Lake Butte des Morts	7903(k)	Carp	whole fish	08/20/1979	5 U
Little Lake Butte des Morts	8001(f)	Northern Pike	whole fish	09/02/1980	5 U
Little Lake Butte des Morts	8002(e)	Carp	whole fish	09/02/1980	5 U
Little Lake Butte des Morts	8003(e)	Walleye	whole fish	09/02/1980	5 U
Little Lake Butte des Morts	8004(d)	White Sucker	whole fish	09/02/1980	5 U
Little Lake Butte des Morts	8101(l)	Walleye	whole fish	08/17/1981	5 U
Little Lake Butte des Morts	8102(j)	White Sucker	whole fish	08/17/1981	5 U
Little Lake Butte des Morts	8103(h)	Carp	whole fish	08/17/1981	5 U
Little Lake Butte des Morts	8201(h)	Walleye	whole fish	09/10/1982	5 U
Little Lake Butte des Morts	8202(h)	White Sucker	whole fish	09/10/1982	5 U
Little Lake Butte des Morts	8203(g)	Carp	whole fish	09/10/1982	5 U
Little Lake Butte des Morts	781A	White Sucker	whole fish	09/06/1978	5 U
Little Lake Butte des Morts	781B	Walleye	whole fish	09/06/1978	5 U
Little Lake Butte des Morts	781C	Carp	whole fish	09/06/1978	5 U
DePere to Green Bay Reach	8405(a)	Walleye	fillet and skin	01/01/1984	5 U
DePere to Green Bay Reach	8406(a)	Walleye	fillet and skin	01/01/1984	5 U
DePere to Green Bay Reach	8407(a)	Carp	fillet and skin	01/01/1984	5 U
DePere to Green Bay Reach	8305(b)	Walleye	whole fish	06/13/1983	5 U
DePere to Green Bay Reach	8308(c)	Carp	whole fish	10/16/1983	5 U
DePere to Green Bay Reach	8403(a)	Carp	whole fish	01/01/1984	5 U
DePere to Green Bay Reach	8404(a)	Carp	whole fish	01/01/1984	5 U
DePere to Green Bay Reach	8601(j)	Walleye	whole fish	10/06/1986	5 U
DePere to Green Bay Reach	8602(h)	Carp	whole fish	10/06/1986	5 U
DePere to Green Bay Reach	8609(e)	Gizzard Shad	whole fish	10/06/1986	5 U
DePere to Green Bay Reach	7801(h)	Carp	whole fish	08/09/1978	5 U
DePere to Green Bay Reach	7802(h)	Carp	whole fish	08/09/1978	5 U
DePere to Green Bay Reach	7803(g)	Walleye	whole fish	08/11/1978	5 U
DePere to Green Bay Reach	7901(a)	Walleye	whole fish	04/04/1979	5 U
DePere to Green Bay Reach	7902(b)	White Sucker	whole fish	04/04/1979	5 U
DePere to Green Bay Reach	7903(b)	Carp	whole fish	04/04/1979	5 U
DePere to Green Bay Reach	8001(h)	Walleye	whole fish	10/02/1980	5 U
DePere to Green Bay Reach	8002(g)	Carp	whole fish	10/02/1980	5 U
DePere to Green Bay Reach	8003(h)	Carp	whole fish	10/02/1980	5 U
DePere to Green Bay Reach	8101(a)	Walleye	whole fish	03/13/1981	5 U
DePere to Green Bay Reach	8102(a)	Walleye	whole fish	03/13/1981	5 U
DePere to Green Bay Reach	8103(j)	White Sucker	whole fish	09/28/1981	5 U
DePere to Green Bay Reach	8104(i)	Walleye	whole fish	09/28/1981	5 U
DePere to Green Bay Reach	8105(h)	Carp	whole fish	09/28/1981	5 U
DePere to Green Bay Reach	8106(f)	Walleye	whole fish	09/28/1981	5 U
DePere to Green Bay Reach	8201(e)	Walleye	whole fish	08/03/1982	5 U
DePere to Green Bay Reach	8202(d)	Carp	whole fish	08/03/1982	5 U
DePere to Green Bay Reach	8203(d)	Carp	whole fish	08/03/1982	5 U
DePere to Green Bay Reach	8101(j)	Carp	whole fish	08/17/1981	5
DePere to Green Bay Reach	7901(b)	Yellow Perch	whole fish	04/04/1979	5 U
DePere to Green Bay Reach	7902(a)	Brown Bullhead	whole fish	04/04/1979	5 U
DePere to Green Bay Reach	7903(a)	Brown Bullhead	whole fish	04/04/1979	5 U

Table 3 Lead Concentrations in Game Fish Tissue Samples

LOCATION	SAMPLE NUMBER	SPECIES	SAMPLE TYPE	SAMPDATE	RESULT (mg/kg)
DePere to Green Bay Reach	7904(k)	Carp	whole fish	10/17/1979	5 U
DePere to Green Bay Reach	7905(j)	Carp	whole fish	10/17/1979	5 U
DePere to Green Bay Reach	7906(f)	Walleye	whole fish	10/17/1979	5 U
DePere to Green Bay Reach	8201(d)	Carp	whole fish	08/03/1982	5 U
DePere to Green Bay Reach	8202(f)	Walleye	whole fish	08/23/1982	5 U
DePere to Green Bay Reach	8307(e)	Carp	whole fish	10/01/1983	0.5 U
Green Bay	7901(c)	Alewife	whole fish	07/05/1979	5 U
Green Bay	7902(h)	Yellow Perch	whole fish	07/05/1979	5 U
Green Bay	7903(h)	White Sucker	whole fish	07/05/1979	5 U
Green Bay	7904(g)	Brown Bullhead	whole fish	07/05/1979	5 U
Green Bay	7905(e)	Carp	whole fish	07/05/1979	5 U
Green Bay	8102(b)	Carp	whole fish	05/14/1981	5
Green Bay	8103(a)	Carp	whole fish	05/14/1981	5
Green Bay	8104(a)	Carp	whole fish	05/14/1981	5
Green Bay	8105(a)	Carp	whole fish	05/14/1981	5
Green Bay	8304(b)	Carp	whole fish	06/01/1983	5 U
Green Bay	8305(a)	Carp	whole fish	06/01/1983	5 U
Green Bay	7901(a)	Lake Trout	whole fish	06/11/1979	5 U
Green Bay	7902(f)	Longnose Sucker	whole fish	06/11/1979	5 U
Green Bay	7903(f)	Burbot	whole fish	06/11/1979	5 U
Green Bay	7904(d)	Rainbow Smelt	whole fish	06/11/1979	5 U
Green Bay	7901(b)	Lake Trout	whole fish	06/25/1979	5 U
Green Bay	7902(g)	Burbot	whole fish	06/25/1979	5 U
Green Bay	7903(g)	Longnose Sucker	whole fish	06/25/1979	5 U
Green Bay	7904(f)	Alewife	whole fish	06/25/1979	5 U
Green Bay	7905(d)	Rainbow Smelt	whole fish	06/25/1979	5 U
Green Bay	7906(d)	Lake Whitefish	whole fish	07/16/1979	5 U
Green Bay	7901(f)	Lake Whitefish	whole fish	07/26/1979	5 U
Green Bay	7901(d)	Rainbow Trout	whole fish	05/17/1979	5 U
Green Bay	7902(d)	Brown Trout	whole fish	05/17/1979	5 U
Green Bay	7903(d)	Lake Whitefish	whole fish	05/17/1979	5 U
Green Bay	7904(e)	Alewife	whole fish	06/15/1979	5 U
Green Bay	8105(e)	Carp	whole fish	06/16/1981	5
Green Bay	7901(e)	Yellow Perch	whole fish	07/12/1979	5 U
Green Bay	7902(j)	Alewife	whole fish	07/12/1979	5 U
Green Bay	7903(j)	Troutperch	whole fish	07/12/1979	5 U
Green Bay	7904(i)	White Sucker	whole fish	07/18/1979	5 U
Green Bay	7905(g)	Black Bullhead	whole fish	07/18/1979	5 U
Green Bay	7901(e)	Brown Trout	whole fish	05/22/1979	5 U
Green Bay	7901(c)	Walleye	whole fish	04/30/1979	5 U
Green Bay	7902(c)	Lake Trout	whole fish	05/02/1979	5 U
Green Bay	7903(c)	Walleye	whole fish	05/08/1979	5 U
Green Bay	7904(b)	Brown Trout	whole fish	05/08/1979	5 U
Green Bay	7905(b)	Rainbow Smelt	whole fish	05/08/1979	5 U
Green Bay	7906(b)	Yellow Perch	whole fish	05/08/1979	5 U
Green Bay	7907(b)	Burbot	whole fish	05/08/1979	5 U
Green Bay	7908(b)	White Sucker	whole fish	05/08/1979	5 U
Green Bay	7909(a)	Northern Pike	whole fish	05/30/1979	5 U
Green Bay	7901(d)	Carp	whole fish	07/06/1979	5 U
Green Bay	7902(i)	Yellow Perch	whole fish	07/06/1979	5 U
Green Bay	7903(i)	Alewife	whole fish	07/06/1979	5 U
Green Bay	7904(h)	Brown Bullhead	whole fish	07/06/1979	5 U
Green Bay	7905(f)	White Sucker	whole fish	07/06/1979	5 U
Green Bay	8106(e)	Carp	whole fish	09/01/1981	5
Green Bay	8108(d)	Carp	whole fish	09/01/1981	5

Table 3 Lead Concentrations in Game Fish Tissue Samples

LOCATION	SAMPLE NUMBER	SPECIES	SAMPLE TYPE	SAMPDATE	RESULT (mg/kg)
Reference	8702(f)	Walleye	fillet and skin	05/12/1987	5 U
Reference	8704(f)	Walleye	fillet and skin	05/15/1987	5 U

Table 4 Lead Concentrations in Waterfowl Tissue Samples

LOCATION	SAMPLE NUMBER	SPECIES	SAMPLE TYPE	SAMPLE DATE	RESULT (mg/kg)
Dunbar Wildlife Area	31B,C (P)	Woodcock	muscle, no skin	09/05/1984	5.00 U
Green Bay	18B,C (P)	Canada Goose	muscle and skin	07/02/1984	5.00 U
Green Bay	11B,C (P)	Mallard	muscle and skin	08/16/1984	5.00 U
Green Bay	84B,C (P)	Mallard	muscle and skin	12/06/1984	5.00 U
Green Bay	18E,F (P)	Canada Goose	muscle, no skin	07/02/1984	5.00 U
Green Bay	11E,F (P)	Mallard	muscle, no skin	08/29/1984	5.00 U
Green Bay	84E,F (P)	Mallard	muscle, no skin	12/06/1984	5.00 U
Little Lake Butte des Morts	08B,C (P)	Mallard	muscle and skin	07/31/1984	5.00 U
Little Lake Butte des Morts	30B,C (P)	Ring-necked Pheasant	muscle, no skin	09/10/1984	5.00 U
Navarino Wildlife Area	10B,C (P)	Common Merganser	muscle and skin	09/07/1984	5.00 U
Navarino Wildlife Area	09B,C (P)	Mallard	muscle and skin	09/14/1984	5.00 U
Rush Lake	04B,C (P)	Mallard	muscle and skin	08/14/1984	5.00 U
Green Bay	96089 (P)	Canada Goose	unknown	06/19/1996	0.09
Green Bay	96092 (P)	Canada Goose	unknown	06/18/1996	0.05
Lincoln Park	96101 (P)	Canada Goose	unknown	06/24/1996	0.07
Oak	97003 (P)	Canada Goose	unknown	06/26/1996	0.13
Regner Park	96098 (P)	Canada Goose	unknown	06/20/1996	0.04
Rock River Golf Course	97016 (P)	Canada Goose	unknown	07/09/1996	0.03
Sheboygan River	96086 (P)	Canada Goose	unknown	06/19/1996	0.07
Spring Lake Park	97006 (P)	Canada Goose	unknown	06/26/1996	0.10
Villa Du Park	96095 (P)	Canada Goose	unknown	06/20/1996	0.04
Wilson Park	96104 (P)	Canada Goose	unknown	06/25/1996	0.06